Development of Biological Aerated Filters: A Review

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Abstract

Biological aerated filters are wastewater-treatment systems which contain support media for the development of a biofilm and provide oxygen at the base of the reactor for aerobic microbial processes. The origins of this type of filter date back to the early 1900s, and modern designs can provide a high level of treatment in small reactor 'footprints'.

This paper provides a review of the technology and development of biological aerated filters and submerged aerated filter systems.

Key words: **Biological aerated filters; submerged aerated filters.**

Introduction

During the past fifteen years, biological aerated filters (BAFs) have become a popular alternative to traditional sewage-treatment systems because of their high-rate treatment characteristics and small footprint(1). BAF reactors are typically used as secondary biological filters for wastewater treatment, but can also be used for many water-treatment applications.

BAF reactors are fixed-film systems in which a biofilm support medium is submerged in wastewater to create a large contact area for aerobic biological treatment. Air or oxygen is introduced at the base of the reactor via a network of diffuser nozzles, discs or tiles (Fig. 1). Normally the support medium has a large specific surface area (140–1500 m^2/m^3) and is manufactured from expanded polystyrene, porous stone, expanded shale or high-voidage plastic media. Two types of high-voidage plastic medium are commonly used, i.e. random packed or modular, and the support medium may be sunken or floating(2). Reactors may be operated as either upflow or downflow systems, where influent is introduced either at the base or top of the reactor respectively.

Basically there are two types of BAF reactor, i.e. backwash and non-backwash systems. Non-backwash BAFs, which are commonly termed 'submerged aerated filters' (SAFs), are simple in design and provide robust performance(2). Many SAF and BAF reactors have been developed by companies working independently, and this has led to a variety of systems and operating criteria.

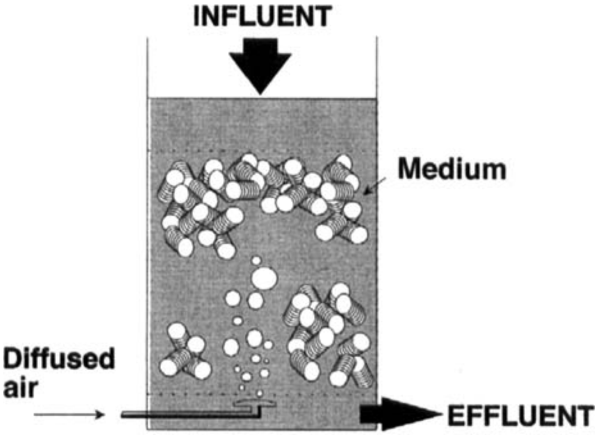

Fig. 1. Typical configuration of a BAF reactor (downflow)

History of BAF

The development of BAF technology commenced in 1913 at Lawrence, USA. The reactor was called a 'submerged contact aerator' (SCA), and was an early type of SAF utilizing layers of slate for the development of biofilm(3).

Between 1925 and 1928, ten full-scale SCAs were developed in Germany, based on the investigations of workers in the USA and Germany. The German SCAs were similar to modern SAFs because there was no backwashing facility; air-scour was used to prevent solids accumulation within the medium, and secondary sedimentation was required. Air-diffuser arms were swung mechanically, in a pendulum motion, beneath the reactors to enhance air-scour and bubble dispersion. Coke and brushwood were initially used as support media, but were unsuccessful due to clogging and were eventually replaced with wooden laths to reduce the accumulation of suspended solids(4).

The German SCAs were typically 3 m deep and featured internal reactor liquor circulation to improve performance as used in some modern SAFs. The SCAs were generally used for pre- or partial treatment of wastewater, and the retention time was 0.5–1.0 h. However, it was suggested that complete biological treatment could be achieved if the retention time was increased to about 4 h. The SCAs were not considered to be economically viable for complete stabilization at that time, because operational and construction costs were higher than for activated-sludge systems.

In 1927, a full-scale SCA was commissioned at Jacksonville, Texas, and was possibly the first such municipal reactor in the USA(5). The plant used brush-

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wood 'faggots' as the support medium and 'filtros plates' for air diffusion, and was designed for a flow of 1800 m^3/d of settled sewage, with a retention time of 1 h. Investigations into the performance of the plant showed that treatment was predominantly a physical process, because of the filtering effect of the wooden medium, and that the final effluent was poorly aerated. The Jacksonville SCA was considered to be about 25% as effective as a biological filter, and its main application was for partial treatment.

A municipal works in Edmonton, Canada, which was constructed in the late 1920s, incorporated a submerged reactor based on the German design. The plant served a population of 8000, with a dry-weather flow of 2200 m^3/d. This SCA demonstrated successful operation, although the effluent quality was not as high as expected from an activated-sludge plant(6).

SCAs were further investigated during the 1930s in Germany, with the development of the Emscher filter (or tank filter) which used coarse slag as the support medium(7). The development of SCAs also continued in the USA, with investigations at Waco, Texas, culminating in the patented design of the 'Hays submerged biological contact filter sewage-treatment plant'(8). By 1943, there were 74 plants being constructed or in operation in the USA using the Hays process(9). The Hays SCAs generally consisted of two upflow reactors in series, with intermediate and final settlement tanks.

Most of the Hays SCAs were located at military establishments and served populations of 500–40 000(10). Early installations used stone or concrete cylinder media, with later versions using asbestos plates held vertically in the reactor. Organic loadings of up to 60 g BOD/m^2. d were reported, with retention times of 1.5–2.5 h. Carbonaceous stabilization levels were typically high – indicated by about 90% BOD removal. The process had several advantages over other sewage-treatment systems, i.e. (a) stability under shock loads, (b) simple operation compared to activated-sludge systems, and (c) compactness. The Hays process was introduced to Canada in the 1950s, where it was reported that the reactors had cost-saving advantages over conventional activated-sludge plants because there was no requirement for returned sludge flow(11). However, the Hays SCAs suffered operational difficulties, typically as a result of poor air distribution(8,10).

In 1967, an experimental aerated wastewater-treatment reactor was developed by the Water Pollution Research Laboratory at Stevenage. The plant aerated settled sewage and utilized PVC tubing as the medium(1); however, research on the pilot plant was discontinued for fear of impinging on a British patent which was issued in 1961 to Albright and Wilson Ltd. The British patented plant was not a true BAF because air was introduced at the top of the reactor(12). In the early 1970s, Lymflo Process Ltd (of Quebec) developed a backwash BAF which was similar to modern BAF reactors. The Lymflo BAF could be operated as either an upflow or downflow filter, and contained low-voidage stratified media of varying particle size requiring regular backwashing. Solids filtration by the media obviated the need for secondary settlement. This system was granted a Canadian patent in August 1974(13), and mechanistic models of BAFs were also constructed around this time(14,15).

Hydraulic Considerations – Upflow and Downflow

BAFs operate as either upflow or downflow reactors, depending upon the position of the influent feed. In upflow systems, influent is introduced at the reactor base and rises co-currently with the process air through the media bed. Downflow reactors are opposingly configured with influent introduced above the media, falling through the media and discharging at the base of the reactor. The advantages of downflow backwash BAFs are reported as having (i) potentially greater particulate filtration, (ii) longer retention times due to the effects of the counter-current airflow and liquor flow, (iii) ease of maintenance, and (iv) lower process airflow requirements(16,17). In comparison, upflow systems are claimed to provide improved biological treatment, require less backwash water volume, and minimize foul odours because treated effluent (and not influent) is in contact with the atmosphere above the reactor(16).

Modern BAFs and SAFs are often similar to early treatment systems such as the SCA and the Lymflo process, indicating the longevity of these systems. Recent developments in BAF technology have refined the original concept, and many differing systems are now available.

Recent BAF Development

During the period 1976–80, the implementation of stringent discharge consents in France encouraged the continued development of backwash BAFs(18). During the 1980s, extensive research on backwash BAF systems was carried out around the world, particularly in France and the USA, producing the basis for many of the BAF systems which are now available(17,19). Most modern large-scale BAFs utilize media with high specific surface areas and low voidage. The reactors are typically designed to treat crude or settled sewage, providing biological treatment and secondary clarification in one reactor. The surface-area requirement is typically very low, and load rates may be in excess of 10 kg COD/m^3. d(18). The high levels of solids retention and biomass development in BAFs necessitate regular backwashing to remove accumulated solids. Backwashing is a complex operation and has to be controlled to ensure that a healthy biomass is retained on the support media.

At present, there are many European companies which manufacture backwash BAFs (Table 1), and most provide a high standard of secondary treatment(17,18,20,21). BAF technology has also been developed and employed in Japan(22). The Biostyr is an upflow BAF utilizing a medium of polystyrene beads (which are less dense than water), and the system has been used in over 100 plants worldwide(23). A recent development by OTV is the B2a – a multi-medium BAF based on the Biostyr system. The medium is graduated from coarse particles (approximately 40 mm dia.) at the base to a finer medium (1–4 mm dia.) in the higher layer. The B2a eliminated a separate primary clarification stage because of the filtering effect of the medium(24).

Backwash BAFs have been successfully applied to wastewater for tertiary nitrification, denitrification, biological phosphorus removal, industrial wastewater treatment and raw water pretreatment(25,26,27).

Table 1. European Backwash BAF Systems[16]

Process	Manufacturer	Flow direction	Support medium	Type of medium
Biobead	Brightwater	Upflow	Polyethylene	Floating
Biocarbone	OTV/Degremont	Downflow	Expanded shale	Sunken
Biofor	Degremont	Upflow	Biolite	Sunken
Biopur	Sulzer/John Brown	Downflow	Polystyrene	Modular
Biostyr	OTV/GWP	Upflow	Polystyrene	Floating
ColOX	Tetra	Upflow	Sand	Sunken
SAFe	PWT Projects	Downflow	Expanded shale	Sunken
Stereau	Purac	Downflow	Pumice	Sunken

Recent SAF Development

Submerged aerated filters have developed from the concept of the earlier SCAs and are essentially BAFs which utilize high-voidage media (typically less than 400 m^2/m^3) but do not require backwashing because accumulated solids in the reactor are controlled by biomass sloughing and air-scouring[28]. Eliminating backwashing reduces construction and operational costs, and generally permits the design of simple reactors with few working parts – enhancing mechanical reliability. SAF reactors are particularly suitable for small plants where robust, simple, compact treatment is desirable. SAFs normally treat settled sewage and require secondary sedimentation.

In 1984, two laboratory-scale upflow SAFs were assessed in Norway[28] as an alternative to RBCs. Research indicated that these SAFs approached a completely mixed reactor flow pattern, suggesting that turbulent mixing was created by the process airflow. Single-stage SAFs were shown to provide a high percentage removal of organic matter at loads of up to 25 g COD/m^2. d, when some degree of nitrification also occurred. It was also demonstrated that operating the two SAFs in series produced a sludge which had better settling characteristics and greater stability than from a single-stage SAF[28]. SAFs were later developed for field-scale treatment[29] and gave good secondary treatment of wastewaters containing municipal and dairy wastes. Pretreatment of heavy dairy loads was achieved at an organic loading of more than 15 kg COD/m^3. d.

During the mid-1980s, an experimental SAF reactor was developed at Kuwait University[30]; this was similar to the Hays process, using media plates held vertically in the reactor. A high percentage removal of organic matter was achieved from a synthetic sewage at loadings of up to 0.09 kg COD/m^2. d. Other workers have demonstrated the effectiveness of SAFs utilizing mineral media (such as quartzitic gravel) and secondary lamella separators[31].

In recent years, several UK manufacturers have used SAFs in small package plants (Fig. 2); these include the WPL HiPAF, the Copa BAF, the Promech FAST™, and a novel BAF incorporating a jet-loop aerator[32,33]. Other systems include the Bio-plus plant (which is similar to the WPL HiPAF), the CAP Technology BAFF, and Tertra Processes ColOX SAF[34]. Reports of these SAFs tend to be vague technical appraisals, providing little identification of factors affecting the treatment performance of the reactors or treatment capacity. Therefore, there is a need to thoroughly investigate and characterize full-scale SAF systems.

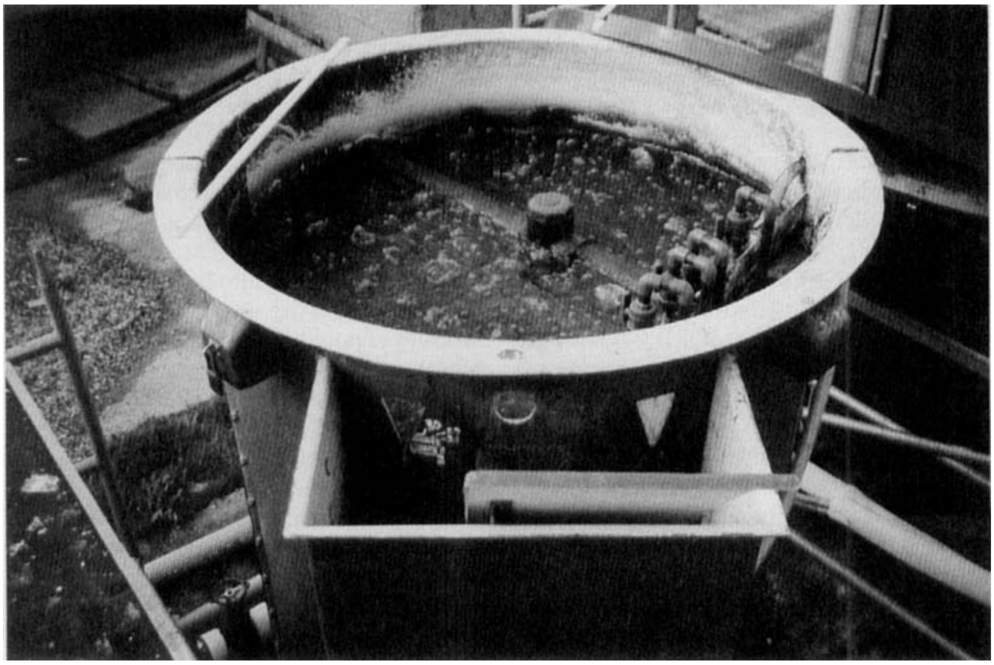

Figure 2. SAF incorporated in small packaged plant

Summary

The high aeration rates which are characteristic of BAF and SAF reactors, together with the large specific surface area of the integral media, allows for high treatment rates to be achieved (Table 2). In comparing these values, it must be remembered that the backwash BAF system does not require secondary sedimentation, unlike the other reactors. Therefore, considerable reductions in land requirement may be possible if backwash BAFs are incorporated in sewage-treatment works. Little comparative treatment performance data for SAF systems exists; however, the experimental SAF described by Velioglu *et al*(31) showed similar load rates to conventional activated-sludge systems.

Table 2. Comparison of typical reactor loadings

Type of reactor	Organic load (g BOD/m^3. d)
Biological filter	100–120
Activated sludge	400–1200
SAF	430
Backwash BAF	3000–8000

Conclusions

1. There are many permutations of BAF and SAF reactors, including different hydraulic regimes and types of support medium. SAFs are BAF reactors which do not require backwashing and typically utilize high-voidage support media.
2. BAFs provide effective secondary treatment and can be used to treat other wastewaters, including commercial and industrial effluents.
3. The high influent loading levels which can be applied to backwash BAFs may permit small footprint installations. High levels of nutrient removal may be attained using BAF systems.
4. During the past two decades there has been considerable development of backwash reactors in Europe and the USA. Because of the high rates of treatment and greater operational complexity, backwash BAFs are normally used in larger treatment plants.
5. SAFs are currently utilized in many package sewage-treatment works because of their robust performance and simple technology. There have been few thorough studies of full-scale SAFs, therefore there is a need to further characterize such systems.

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