Chapter 13

Aerobic Biofilters

13.1 INTRODUCTION

Aerobic biofilters (also known as 'trickling filters' of 'percolating filters') have been in use for the treatment of organic wastewaters since the early 1900s. They were originally developed from the practice of sewage treatment by application to land, or 'sewage farming' as it was known in the nineteenth century. Attempts to improve the efficiency of land treatment led to the discovery in about 1888 that settled sewage could be purified by passing it through an artificial bed of coarse porous medium at about 10 times the application rate for conventional land treatment. Following this discovery, percolating filters were developed fairly rapidly and by 1908 this method had become the standard method of accelerated sewage purification. Today, in the first decade of the 21st. century, aerobic biofilters compete somewhat unsuccessfully with the activated sludge process for the purification of dilute organic wastewaters, while high-rate biofilters are sometimes used for the partial treatment of strong organic wastewaters.

Aerobic biofilters may be classified as biological reactors of the attached film/static medium type. The medium most widely used is natural stone (50-100mm size), as illustrated in Fig 13.1, while a variety of purpose-made plastic media is also available.

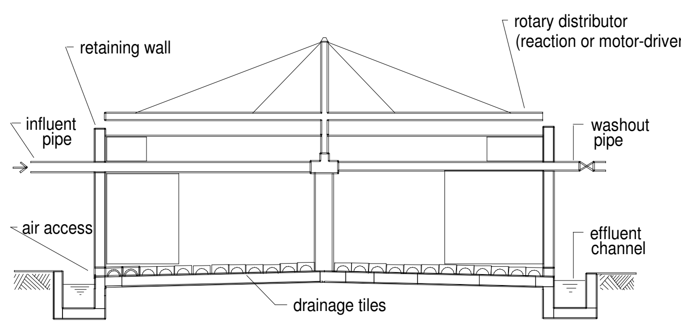

Fig 13.1 Schematic layout of stone-filled filter

13.2 MODE OF ACTION

The mechanism of removal of organics is similar to that of the activated sludge process. The greater portion of the liquid applied to the surface of the filter passes rapidly through and the remainder trickles slowly over the surface of the slime growth. The removal of organic colloids in suspension and dissolved substances by 'biosorption' and coagulation from that portion of the flow that passes through rapidly, and by the usual processes of synthesis and respiration from the part of the flow with long residence time. This residence time is primarily related to the hydraulic loading, so it seems reasonable that the greater the hydraulic loading the more the process will depend upon biosorption and the less it will depend upon synthesis and respiration, other things being equal.

The action of the filter depends on the metabolic activity of zoogleal or filamentous bacteria or of fungi. These colonize the extensive surfaces of the support medium and form the basis of the 'film', which also contains a population of protozoa as well as amorphous solids, derived from the waste. Algal growths may

also be present in the upper regions of the filter exposed to light. A population of macro-organisms is also usually found to be associated with the film. The composition of the microbial population is dependent on the nature of the waste, its strength, the rate at which it is applied and the method of operation of the filter. Therefore the film may range in character from a tenuous bacterial slime in a filter receiving waste of low organic content, to a thick mass of fungal mycelium in a filter treating strong sewage containing certain types of industrial wastes.

The reduction in concentration of polluting matter occurs most rapidly in the upper regions of the filter. In a conventional filter treating settled domestic sewage, about 90% of the biodegradable matter may be removed in the upper 0.6m of the bed (see Fig 13.2). The net removal rate of organic matter is a function of the immediate removal of the readily biodegradable fraction and the release of products of endogenous metabolism of the biofilm. When ammonia is present in the waste, as in the case of municipal sewage, its removal by microbial nitrification occurs largely in the middle and lower regions of the filter. The zones of carbonaceous oxidation and nitrification are not sharply defined, but conditions for the growth of nitrifying bacteria tend to be more favourable in the lower parts of the filter where the content of oxidizable organic matter in the waste has been reduced and where the oxygen concentration in the film is therefore higher.

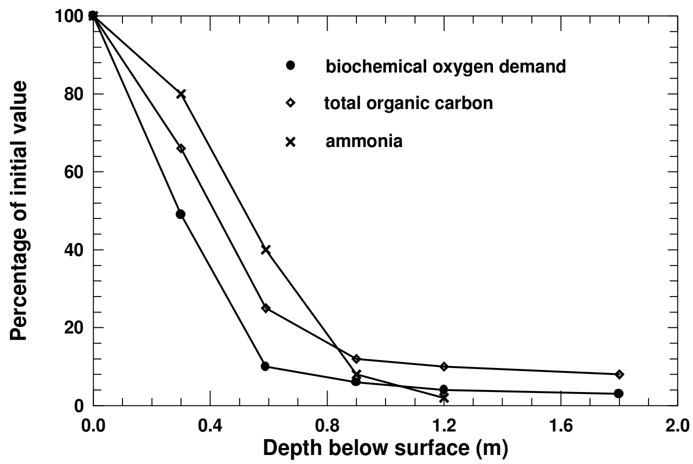

Fig 13.2 **Substrate removal over the depth of a biofilter**
(Bruce, 1969)

Mechanical filtration is not an important part of the purification mechanism, so that the term ‘filter’ is a misnomer persisting from the early days when the nature of the process was misunderstood. Although solids present in the waste may be physically trapped by the medium or the film matrix, it is essential for the satisfactory operation of conventional filters to remove as much coarse suspended matter as possible by primary sedimentation.

As a result of the growth of bacterial cells and the deposition of coagulated solids from the waste, the quantity of film within the filter tends to increase. The growth rate is dependent on the concentration of biodegradable organic matter in the waste and on the application rate. The growth of film tends to be greatest in the upper regions of the filter where the largest proportion of the substrate is removed. If the growth rate of the film exceeds its removal rate by other mechanisms, the interstices of the medium will ultimately become choked, impeding the flow through the bed and restricting ventilation. In the extreme, the surface of the filter may become ponded. The clogging of the medium with accumulated film is the most serious problem in the operation of conventional filter beds and it the factor that limits the maximum rate at which wastes can be treated efficiently by such plants.

13.3 BIOFILTER ECOLOGY

The biological film or slime layer is inhabited by an interdependent microbial population, including bacteria, fungi, protozoa and a variety of macroinvertebrates (Bruce 1969). Algae are restricted to the surface of the bed, where light is available. They play a minor role in the purification process, but excessive growth can cause blinding of the surface.

The thickness of film, which can be maintained in an aerobic condition by diffusion of atmospheric oxygen through the film surface, is rather limited. Estimates of the aerobic zone in an actively respiring film vary between 0.06 and 2mm, while in deeper regions of the film anaerobic conditions prevail.

Macroinvertebrates include a variety of worms, insect larvae and snails. They serve a useful role in film disintegration, especially in low-rate filters, where the scouring effect of the liquid flow is rather limited.

One disadvantage of the presence of fly larvae in a filter is the emergence of adult flies, particularly *Psychoda* and *Anisopus*, which may cause a serious nuisance in the warmer months. Various methods (Tomlinson and Jenkins, 1947) for controlling the fly population have been used including treatment of the filter with lime, creosote, bleaching powder and salt. The most effective method of artificial control is to use an efficient insecticide in amounts sufficient to kill the flies and their larvae without affecting the worms and other animals in the filter, and also without rendering the effluent toxic to fish. It has been suggested that the only long-term solution to the problem lies in the suppression of the fly population by a dominant population of worms competing for the available food supply.

13.4 TEMPERATURE EFFECTS

All biological processes are affected by temperature, as discussed in Chapters 11 and 12. The biofilm in percolating filters is very vulnerable to temperature change, which may result from a change in the incoming wastewater, or in the environmental air circulating through the filter or both. The exposure of the influent liquid to air in the form of a thin film facilitates both oxygen and heat transfer. In this respect, percolating filters experience a greater annual temperature fluctuation than do activated sludge processes.

The effect of the decline in the temperature of sewage during the winter months is to reduce the activity of the macroinvertebrates. The growth rate of the film may also be reduced with temperature but generally to a smaller extent, and a net accumulation of film usually results. This may cause partial or complete blocking of the medium. Fungal growths flourish and at the same time worms and fly larvae, which would be present in the surface layers during the summer, retreat into the depths of the bed. The unequal effects of low temperature on film growth and animal activity limits the rate at which sewage can be applied to a filter, if an effluent of good quality is to be achieved. The arrival of warmer weather gives rise to a fairly rapid depletion of accumulated film in percolating filters and a corresponding increase in the concentration of suspended matter in the effluent. This phenomenon has not been completely explained. It has been attributed to the increased activity of the fly and worm populations in response to a temperature rise and also to microbial lysis within the film. A marked sensitivity to temperature was observed in pilot plant studies on high-rate filters (Bruce, 1971), the minimum winter BOD removal rate being less than half the maximum summer BOD removal rate.

13.5 PROCESS DESIGN

13.5.1 Design parameters

Where the influent wastewater contains settleable solids primary sedimentation is necessary to avoid ponding problems on the biofilter medium surface. The key design loading parameters for fixed media aerobic biofilters are:

- wastewater irrigation rate ($m^3\ m^{-2}\ d^{-1}$, based on plan area of filter)
- organic space loading rate (kg $BOD_5\ m^{-3}\ d^{-1}$)
- operating temperature
- oxygen availability

The wastewater irrigation rate must exceed the minimum value required to fully wet the entire surface area of the medium. With rotating distributors liquid discharge over the surface of the biofilm is cyclical, whereas with fixed distribution manifolds the distribution is continuous but may be somewhat non-uniform. In general, biotowers containing plastic media with a very high specific surface require recirculation of effluent to ensure full wetting of the media.

While the organic space loading rate (kg $BOD_5\ m^{-3}\ d^{-1}$) is a convenient design parameter, the biofilm organic loading rate expressed as g $BOD_5\ m^{-2}\ d^{-1}$ provides a more useful index of process performance. The latter parameter is similar to the sludge loading rate (SLR) parameter in activated sludge processes.

Oxygen transfer is effected in biofiltration processes by the creation and renewal of air-water interfaces and the turbulent mixing that occurs in the complex pathways of liquid movement through filter media. The process requires free air movement through the filter voids; hence adequate ventilation is essential for the satisfactory functioning of biofilters.

The properties of biofilter media of particular relevance to process design/performance are:

- specific surface area ($m^2\ m^{-3}$)
- voids ratio (void volume/total volume)
- nature of flow path through the medium

As already noted the nature of the flow path influences the hydraulic retention time oxygen transfer. The latter is enhanced by a medium configuration that promotes rapid air-water interface renewal.

Because of the complexity of biofiltration processes, a reliable predictive model of process performance, taking into account all the foregoing parameters is not available. Aerobic biofilters are classified as low-rate or high-rate, depending on the applied hydraulic and organic loading rates. Loading parameter ranges for both categories are summarized in Table 13.1. The conventional low-rate biofilter used in municipal wastewater treatment, is typically loaded at about 0.1 kg $BOD_5\ m^{-3}d^{-1}$, the corresponding hydraulic loading rate being about 1 $m^3m^{-2}d^{-1}$. Low-rate filters generally achieve a significant degree of nitrification at favourable process temperatures (>15 ^oC). Empirical evidence (USEPA, 1993) indicates:

(a) the onset of nitrification will likely not occur unless the soluble BOD_5 surface loading rate is less than 9 g $m^{-2}\ d^{-1}$.

(b) Nearly complete nitrification (effluent NH_3-N of about 2 mg l^{-1}) will typically be encountered at a soluble BOD_5 loading rate of about 2 g $m^{-2}\ d^{-1}$.

Table 13.1

Parameter	Low-rate biofilter	High-rate biofilter
Hydraulic loading rate ($m^3\ m^{-2}\ d^{-1}$)	1-4	10-40
Organic space loading rate (kg $BOD_5\ m^{-3}\ d^{-1}$	0.1-0.3	0.3-2.0
Biofilm loading rate (g $BOD_5\ m^{-2}\ d^{-1}$)	2.5-7.5	7.5-20
Depth (m)*	1.5-3.0	1.5-6.0
Recirculation	none	usual

*Stone and similar solid aggregate media filters are generally not more than 2m in depth, while high-rate plastic media filters may be up to 6m deep (so-called biotowers).

13.5.2 Biofilter media

The essential requirements for a filter medium are that it should be inert, be of sound mechanical strength, and possess within its bulk an extensive area of exposed surfaces over which the liquid to be treated can be passed. Adequate void spaces must exist between adjacent surfaces to allow for some accumulation of biofilm, for free passage of liquid and suspended matter, and for access of air. Performance can be correlated with the specific surface of the medium, provided that the degree of film accumulation is not such as to cause clogging. Thus with low film conditions, a 25 mm solid medium of a given type may be expected to produce a better effluent than a 50mm medium of the same type. Also, for a given size of medium, rough-surfaced materials such as clinker have a marginally superior performance to that of smooth materials such as natural pebble.

A variety of light-weight plastic biofilter media are available, providing much higher specific surface area and voids ratio than stone or clinker, as the typical data in Table 13.2 indicate.

Table 13.2 Filter media characteristics

Medium type	Size/arrangement	Specific surface ($m^2\ m^{-3}$)	Voids (%)
Stone/clinker	50-100mm, random packing	40-50	50-55
Plastic	Various	100-200	>90

13.5.3 Recirculation

Recirculation provides a measure of flexibility in the design of high-rate filters. Recirculation options are illustrated in Fig 13.3. Normally, recirculation is from the biofilter outflow to the biofilter inflow. Alternatively, there is the option of including either the upstream or downstream clarifier in the recirculation loop, in which case the included clarifier has to be designed for a flow of Q(1+R), where Q is the inflow rate and RQ is the recycle flow rate.

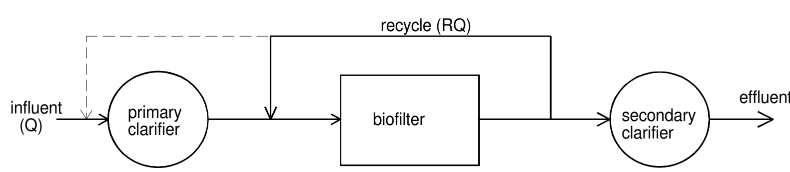

Fig 13.3 **Biofilter re-circulation options**

The main process influences of recirculation are (a) dilution of the influent strength, and (b) increased and also less variable wetting rate of the biofilter medium. The latter is particularly important in high-rate filters containing plastic media with a high specific surface area.

The dilution effect of recirculation is quantified by the expression:

$$D_R = \frac{1+R}{1+R\dfrac{C_R}{C_i}} \qquad (13.1)$$

where D_R is the influent dilution ratio, that is, influent concentration in the absence of recirculation/influent concentration with recirculation; C_R is the substrate concentration in the recycled flow, and C_i is the biofilter influent concentration at zero recirculation. While recirculation reduces the strength of the wastewater being applied to the biofilter, it should be noted that it increases the overall organic loading.

13.5.4 Influent distribution

The standard method of influent irrigation on circular biofilters is by rotary distributor, which consists of two or more arms, mounted on a pivot at the centre of the biofilter and revolving in a horizontal plane, as illustrated in Fig 13.1. Each arm is designed as a distribution manifold with discharged points so spaced as to secure a uniform irrigation of wastewater over the entire bed area (requires decreasing discharge nozzle spacing with distance from the centre of rotation). The distributor may be driven by the jet reaction of the nozzle discharges or by a geared motor. The speed of rotation is selected to give an application interval of 4-12 minutes, which has been found (Tomlinson and Hall, 1955) to give satisfactory performance. A clearance of 0.15m is usually allowed between the underside of the distributor arm and the top of the bed. Motor-driven distributors have the advantage of providing a constant rotational speed, while the speed of reaction-driven distributors is determined by the flow rate. In small-scale units of the latter type, the inflow rate may be syphon-controlled to secure a measure of uniformity in application rate and hence in the distributor rotational speed.

Wastewater irrigation systems for rectangular biofilters generally incorporate a travelling manifold, which traverses the filter in both directions. A fixed manifold distribution system is normally used for wastewater irrigation on biotowers (deep-bed filters). These units incorporate self-supporting plastic media and may be up to 6m deep. Biotowers are typically used at high hydraulic and organic loading rates to achieve 40-70% BOD reduction. A typical biotower layout is shown in Fig 13.4.

13.5.5 Biofilter ventilation

The ventilation of biofilters takes place by convective air movement through the medium due to a temperature-related density difference between the filter air and the ambient air. It is therefore important to provide adequate air openings at the base of the medium to facilitate natural ventilation. Such ventilation is conveniently provided by designing the under-drain collector system to flow partly filled, so that it acts as an air distribution system, and by ensuring that it is adequately vented. A total vent area of 0.4% of the plan area of the filter has been proposed (Metcalf & Eddy, Inc. 1991) as a design guide.

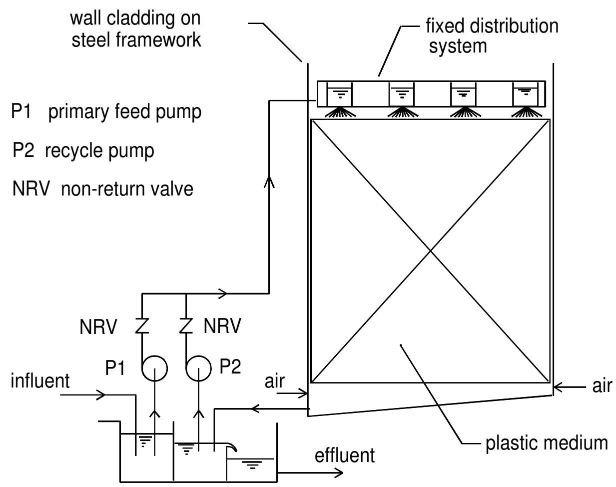

Fig 13.4 **Typical biotower configuration**

13.5.6 Alternating double filtration

Alternating double filtration (ADF) is a particular configuration of biofilter treatment system used for the treatment of relatively high-strength biodegradable industrial wastewaters such as produced in the dairy industry. ADF consists of two biofilters operating in series, each with its own sedimentation tank. At intervals from daily to weekly, the order of the filters is reversed. The relegation of one of the filters to a secondary role causes depletion in accumulated film and hence controls clogging. Thus, while a single low-rate biofilter might be subject to excessive film growth if the applied BOD_5 concentration exceeded 500 mg l^{-1}, the ADF arrangement overcomes this difficulty. It should be noted that much the same end result would be achieved by recirculation.

13.6 SLUDGE PRODUCTION IN BIOFILTERS

The slime layer material discharged from static media aerobic biofilters is commonly referred to as humus sludge. There is little published data on biofilter sludge production. The rate of humus sludge production in low-rate pilot plant biofilters has been reported (Bruce and Boon, 1970) to vary within the range 0.08-0.5 kg per kg BOD_5 removed, the higher value relating to springtime, when there is a marked shedding of filter slime and the lower value relating to summer time. The corresponding mean rate of film discharge was found to be 0.22 kg per kg BOD_5 removed, which agrees reasonably well with observed activated sludge production rates in extended aeration systems (see Chapter 12). The average rate of sludge production from high-rate pilot plants, treating settled domestic sewage, has been found (Bruce and Boon, 1970) to be in the range 0.63-1.0 kg per kg BOD_5 removed, with little seasonal variation in this range.

13.7 ROTATING BIOLOGICAL CONTACTOR

The rotating biological contactor (RBC) is an attached biofilm system, which typically consists of a series of circular discs (biodisk) mounted on a horizontal shaft placed in a semi-circular trough with

approximately 40-45% disk submergence. Alternatively, a cylindrical mesh drum filled with random plastic packing (biodrum) may be used. The biodisk or biodrum is rotated at a speed that allows adequate attached biofilm development. Oxygen transfer is achieved by exposure and renewal of air-water interfaces as the contactor rotates and the wastewater is lifted by the rotating device and trickles back down into the sump. This cyclic immersion of the biofilm also provides the opportunity for the adsorption and uptake of organics from the wastewater. Although the concept was first put forward by Weigand in 1900 and subsequently tested by Doman in 1929, the process was not commercially developed as a wastewater treatment process until the 1960s (Huang and Bates, 1980).

While many types of proprietary RBC systems have been developed, mainly for small-scale application (<500 PE), they generally conform to the following design parameter ranges:

disc or drum diameter:	0.7-3.5 m
rotational speed:	0.5-10 rpm
biofilm loading:	3-6 g BOD_5 m^{-2} d^{-1}

As in conventional biofiltration processes, the RBC process requires pre-treatment by primary sedimentation and post-treatment by secondary sedimentation. Experimental biodisk studies (Bruce and Merkens, 1975), treating settled domestic sewage, have shown that where the biofilm loading is less than about 6 g BOD_5 m^{-2} d^{-1}, a settled effluent BOD_5 less than 20 mg l^{-1} can be obtained. The trough volume is determined by the design biofilm loading rate and the strength of the settled wastewater. It has been found advantageous (Pike et al., 1982) to subdivide the trough into a set of chambers in series, thus simulating a plug-flow regime and hence increasing the average conversion rate for the process unit.

RBCs are vulnerable to freeze-up and subsequent mechanical damage in cold weather and hence are normally covered in climates subject to freezing conditions.

13.8 SUBMERGED ATTACHED BIOFILM PROCESSES

Three reactor types merit inclusion under the general heading of submerged attached biofilm processes. They are (a) packed-bed reactors, (b) biological aerated filters, and (c) fluidized-bed reactors. Unlike percolating filters, they share the common feature that the filter medium is submerged.

The packed-bed bioreactor operates in an upflow mode and may incorporate the same range of media used in conventional percolating filters. The medium is stationary and is not expanded by the upward liquid and air flows – hence the term packed-bed. These reactors require an inflow manifold distribution system at floor level to ensure a uniform flow distribution over the tank plan area. An aeration system, similar to that used in the activated sludge process, is required to generate the dissolved oxygen required for biofilm respiration.

The biologoical aerated filter (BAF) operates in downflow mode in a manner similar to the rapid gravity filters used in drinking water production, albeit used a coarser granular medium, typical in the range 2-6mm. The effluent is collected in an under-drain system at the base of the filter. Aeration is by a diffused air system with diffusers located near the base of the filter. The retained suspended solids and discharged biofilm are removed from the filter by backwashing , usually with air and filtrate. The back-wash flow is typically returned to the primary clarifier for solids separation. The filtrate does not require secondary clarification.

Fluidized-bed biofilm reactors, also called expanded bed reactors, are submerged media reactors operating in an up-flow mode. The medium used is generally either silica sand or granular activated carbon. The up-flow velocity must be sufficient to fluidize the bed such that individual grains are effectively separated from neighbouring grains. Fluidized bed reactors have the potential to operate at a much higher biomass concentration than feasible in activated sludge processes. Aeration systems similar to those used in the activated sludge process are used to supply the dissolved oxygen required for biofilm respiration. Careful

attention to hydraulic design is required to ensure the required degree of bed expansion, while at the same time ensuring that there is no loss of media from the reactor.

13.9 COMPARISON OF ACTIVATED SLUDGE AND BIOFILTER PROCESSES

The main advantages of biofilter processes over activated sludge (AS) systems are: (i) attached biofilms are not susceptible to the 'sludge bulking' phenomenon, which can significantly reduce the treatment efficiency of AS processes, (ii) in its low-rate form, the aerobic biofilter uses less energy than the AS process.

The main disadvantages are: (i) to achieve the same degree of BOD removal, aerobic biofilters require a much larger process volume than the AS process; pre-sedimentation is also required for wastewaters containing settleable solids. Hence, the capital cost of biofilter systems may be significantly higher than that for AS systems. (ii) biofilters are operationally less flexible than AS systems; biofilter systems suffer a greater reduction in performance at low temperature than do AS processes; it is not feasible to incorporate de-nitrification into biofilter systems . (iii) under certain conditions, biofilter systems may give rise to odour nuisance (high-rate systems) and fly nuisance (low-rate systems).

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