DEPARTMENT OF WATER AFFAIRS & FORESTRY

CODE OF PRACTICE: VOLUME 3

BIOLOGICAL FILTRATION SYSTEMS
(TRICKLING FILTERS)

GENERAL GUIDELINES

(JULY 2008)

CONTENTS

TERMS FREQUENTLY USED

General

Aerobic:	Condition/environment where adequate free oxygen is available for aerobic microorganisms to grow – the electron acceptor is molecular oxygen (O_2) and latter is reduced to water (H_2O).
Anaerobic:	Condition/environment lacking oxygen where only anaerobic microorganisms can grow – no O_2, NO_2^- or NO_3^- is present and the organism generates its own electron acceptor internally.
Biological Filter:	Biological process whereby sewage is distributed and slowly trickles over a bed containing media that houses microorganisms. Latter oxidise the biodegradable matter contained in sewage aerobically.
DWAF:	Department of Water Affairs and Forestry.
Media:	Host or attachment material on which microorganisms can grow.
PE:	Population Equivalent. This term is used to express the total flow and load discharged into a sewage works in terms of population, e.g. number of users.
Primary:	Generally the first stage of a treatment process.
Pond System:	System of dams that are designed to receive and treat wastewater, utilising mainly natural resources, e.g. solar energy, algae and a variety of microorganisms, to physically and biologically remove solids, organic matter, nutrients and reduce pathogens. Often called lagoons, e.g. USA.
Retention Period:	Average time that liquids or solids are retained in a containment structure.
Septic Tank:	Tank that collects and contains sewage for a specific period.
Secondary:	Treatment process that follows the primary treatment stage.
Tertiary:	All treatment processes that follow a secondary treatment stage.

Chemical

BOD:	Biodegradable Oxygen Demand = measurement of oxygen utilized by microorganisms during oxidation of organic material contained in wastewater.
BOD_5:	Oxygen utilized within 5 days (BOD_5) of microbial activity. This duration was selected to minimize the effect of nitrification.
COD:	Chemical Oxygen Demand = measurement of the amount of oxidisable organic matter, *viz* the amount of oxygen required to convert all organic carbon constituents to CO_2 and H_2O.
DO:	Dissolved Oxygen = measurement of the dissolved oxygen available in a water body.
DOL:	Daily Organic Load = people served times BOD or COD discharged per person per day.

Flow

ADWF:	Average Dry Weather Flow = average total quantity of sewage received per day divided by 24 hours.
PDWF:	Peak Dry Weather Flow = maximum flow during peak hours. Generally assumed (if not specifically measured) as twice the ADWF.
AWWF:	Average Wet Weather Flow = average flow during the rainy season, which includes rain- and groundwater infiltration into the sewer. Generally assumed (if not specifically measured) as three times ADWF.

1. INTRODUCTION

In the Water Resources Management Act, 2004 (Act No. 24 of 2004), there are conditions to facilitate the proper operation of different sewage treatment systems and their methods of disposal. It indicates ways on how to properly use and protect one of our most valuable natural resources, namely water, and to encourage reuse of the treated effluent.

Biological treatment processes, which include activated sludge processes, trickling filters (biofilter), oxidation ponds and even the self-purification powers of rivers, all operate on essentially the same fundamental biochemical principles. They differ from one another primarily in the method of adding and utilising dissolved oxygen. In this manual, biological filtration as a treatment process will be addressed.

The construction, operation and disposal of effluent using a biological filtration system is subject to a wastewater discharge permit from the Department of Water Affairs and Forestry (DWAF).

Definition: Biological filtration in sewage treatment applications relies on microorganisms growing on a specific surface that is wetted with the effluent. It falls into the category of attached-growth processes and is typically applied in trickling filter technology and biorotors.

Trickling filters have been in use throughout the world for many years. Substantial research during the last fifty years has seen new developments in this field, to such an extend that “new generation” trickling filter technology can now be employed to produce a final effluent complying with the currently applicable Namibian standards for effluent discharge, *viz* the General Standards of Act No. 24 of 2004. Therefore, final effluent from a well-designed and properly maintained trickling filter system can be discarded into the environment and is suitable for limited reused, e.g. gardening, lawns and certain agricultural produce. Since water is a scarce commodity in Namibia, reuse thereof is strongly encouraged. A reuse permit obtainable from DWAF is required for this purpose.

Modern trickling filter technology has a wide range of applications. It is used to treat domestic sewage as well as organically laden industrial effluents. On the sewage side, this technology has not only been employed successfully in small scale starting at 20 people, e.g. for lodges, schools, rural communities and small towns, but has also been used extensively in larger cities with populations far in excess of 300 000 people, e.g. in India and South America.

This manual addresses treatment of wastewater by means of biological filtration systems. It includes basic design information and strives to present information that may be helpful to those performing compliance inspections, sampling and writing or assessing technical reports on which permit conditions are based. However, new generation trickling filter technology is fairly complex and only a specialist in this field should design new plants.

2. BACKGROUND INFORMATION

Some background information on sewage characterisation needs to be given before the principles of biological filtration can be further elucidated.

2.1 DOMESTIC SEWAGE CHARACTERISATION

Domestic sewage is a diluted suspension of human discharges in water. The polluting material is mainly of an organic nature (organic carbon) and ammonia nitrogen (main constituent of urine). Organic material consists of a soluble and insoluble portion, each again with a biologically degradable and undegradable fraction.

The strength of sewage is indirectly obtained by determining chemically the amount of oxygen required to fully oxidize organic and inorganic matter to carbon dioxide and water. A wastewater expert should be consulted to determine the flow and make-up of sewage for each particular set-up.

2.1.1 FLOWRATES

The amount of sewage generated is classified in terms of different flows that can reach a treatment plant and is expressed as:

- AVERAGE DRY WEATHER FLOW (ADWF). The average dry weather flow is the average total quantity of sewage received per day divided by 24 hours and must be averaged over 12 months. For example, average sewage received over the last year was 10 m^3 a day:

  ADWF = 10 000 ℓ/d ÷ 24 h = 417 ℓ/h; Design for ADWF = 420 ℓ/h

- PEAK DRY WEATHER FLOW (PDWF). Peak dry weather flows are maximum discharge figures into a plant (or septic tank) during a specific day when it is not raining. It is usually assumed that this figure is double the ADWF. From above example:

  PDWF = 840 ℓ/h

- AVERAGE WET WEATHER FLOW (AWWF). The wet weather flows are maximum flow rates recorded during the rainy season and include infiltrated (rain) water into the sewer. It is usually estimated to be three times the average dry weather flow. From above example:

  AWWF = 1 260 ℓ/h

Please note, care must be taken in the design and lay-out of a town to prevent stormwater from being collected and directed into the sewage reticulation network. This specifically applies to stormwater run-off on individual premises, roads, parking areas and sports fields. Reason being, that stormwater, if discharged into a treatment plant, places a high instantaneous hydraulic load on the plant (for which treatment plants are not designed) and will result in washout of micro-organisms especially in submerged-growth systems such as activated sludge plants.

2.1.2 LOAD (SEWAGE STRENGTH)

The strength of sewage arriving at treatment works varies considerably, depending largely upon the domestic living standards of the contributing population. Main constituents taken into consideration to characterise sewage include:

- Oxidisable organic material, or substrate e.g. COD or BOD;
- Nutrients, mainly N and P;
- Solids concentration.

The loading of a treatment plant is the quantity of polluted water that will flow into the system per day and determines the size of the system. The following are the most common parameters used to measure organic matter:

- Chemical Oxygen Demand (COD)

  The COD test measures the amount of oxygen required to chemically oxidise organic compounds in the wastewater to carbon dioxide and water. Treatment plant designs are based on the daily COD load that is discharged into the works. It is therefore important to obtain a fairly accurate figure for design purposes. The test itself takes about 4 hours.

- Five-day Biochemical Oxygen Demand (BOD_5)

  The BOD test measures the quantity of biologically degradable organic matter in a wastewater in terms of the amount of oxygen required by microorganisms to oxidise it to carbon dioxide and water. The test is usually conducted over a period of five days and therefore called BOD_5.

In domestic sewages there is a fairly constant COD/BOD_5 ratio of about 2:1. As a general approximation, it may be assumed that the organic load discharged by humans is approximately 100 g COD per person per day (DWA, 1998).

A wastewater expert should be consulted to determine the make-up, volume and strength of sewage for each particular set-up. COD and BOD tests are complex and should be undertaken by an approved and recognised (in the wastewater treatment field) analytical laboratory only.

2.2 ESTIMATING ORGANIC LOAD

The daily organic load, either expressed as COD or BOD, is used as the main design parameter for sizing biological treatment plants. This figure can be estimated from the number of people that discharge wastewater into the treatment works but may vary depending on the diet and social structure of the population served. For design purposes the load estimation criteria as given in Table 1 can be used.

TABLE 1. Load Estimation Criteria (Voysey 1988) per Capita

Type of Area Serviced	Hydraulic load l/p*/d	Organic load (g BOD/p*/d)	Organic load (g COD/p*/d)
Affluent residential area, fully sewered	135-200	54-60	115-130
Residential area with denser housing > 20 houses/ha, fully sewered.	80-150	50-56	105-120
Conservancy tank, contents carted to ponds, with bathrooms, basins and kitchen sinks connected.	80-150	45-54	96-115
Conservancy tanks (or septic tanks) with no bathwater, basins and kitchen sinks connected.	50-60	35-40	75-85
Townships with water supply standpipes and externally collected wastewater.	50-60	35-45	75-96
Load for night-soil pond system.	---	36	76

* p denotes person (= per Capita)

Average concentration of the BOD of raw wastewater discharged into a pond system can be calculated using the above Table as follows:

$$P_o = (b/q).10^3$$

Where: P_o = BOD concentration in the influent to the pond (mg/l)
b = BOD contribution per person per day (g BOD/p/d)
q = Effluent discharged per person per day (l/p/d)

2.3 INDUSTRIAL WASTEWATERS

There is no “typical” composition for wastewaters discharged by different industries. The COD of an industrial effluent can be as low as 100 mg/l, or even as high as 350 000 mg/l (e.g. synthetic petroleum industry). Also, when comparing wastewaters discharged by similar industries but in different plants, large discrepancies in constituents have been found to exist. The reason being, that even a small change in water management policy by the individual plant operators can result in totally different compositions and volumes of final effluent being produced.

For design and evaluation purposes each industrial plant must therefore be treated as unique and a full assessment of each effluent stream of its **COD and especially BOD** must be undertaken. Table 2 shows how the relationship between COD and BOD values can differ even in the medium to low COD-ranges of various industrial effluents when full biological treatment is employed. However, it needs to be stressed that these are indications only and each effluent needs to be analysed to determine its true composition and biodegradability.

TABLE 2. COD, BOD relationships for different Industrial Effluents (Eckenfelder, 1996)

	Influent		**Effluent**	
Wastewater	**BOD (mg/L)**	**COD (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**
Pharmaceutical	3,290	5,780	23	561
Diversified Chemical	725	1,487	6	257
Cellulose	1,250	3,455	58	1,015
Tannery	1,160	4,360	54	561
Protein Process	3,178	5,355	5	245
Tobacco	2,420	4,270	139	546
Paper Mill	380	686	7	75
Vegetable Oil	3,474	6,302	76	332
Vegetable Tannery	2,396	11,663	92	1,578
Hardboard	3,725	5,827	58	643
Saline Organic Chemical	3,171	8,597	82	3,311
Coke Ovens	1,618	2,291	52	434
Coal Liquid	2,070	3,160	12	378
Textile Dye (organic base)	393	951	20	261
Kraft Paper Mill	308	1,153	7	575

3. BIOLOGICAL FILTRATION

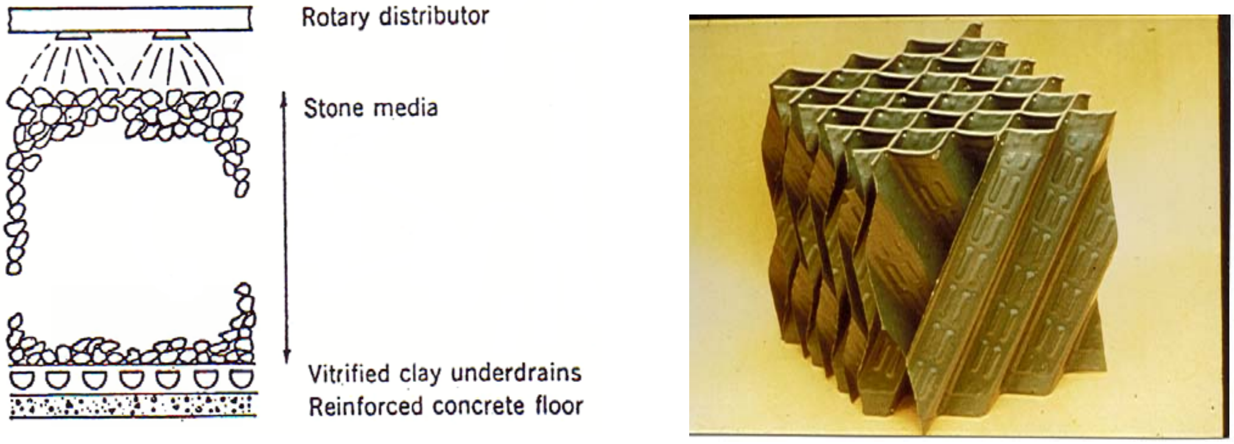
3.1 BACKGROUND

A biological filter is not a filtration system as such, but rather provides a bed for microorganisms to establish themselves and to utilise (oxidise) the organic matter contained in sewage as food and thereby “cleaning” the effluent. It can therefore be described as a fixed-film reactor in the shape of a packed tower. Thus, the biological filter establishes a natural environment that consists of a bed of highly permeable medium that serves as host for microorganisms to attach to and through which wastewater is percolated and treated.

Stratification of microorganisms takes place in the filter, because the organic load in the wastewater at the top of the bed is higher than the water reaching the lower part. Although classified as an aerobic treatment process, the biofilter is not a truly aerobic system. It rather consists of a diverse biological system ranging from truly aerobic to anaerobic microorganisms in symbiosis, similar to a facultative system. However, sufficient oxygen must be available in the bed, because aerobic microorganisms and processes constitute the major form of treatment in such a system.

3.1.1 Filter Media.

The filter medium can be made up of a bed of granular material such as crushed stones, or various types and shapes of plastic packing material. Whereas stone media has been widely used in the past, the new generation trickling filters now use plastic media. Reason being, plastic media provides a much larger specific surface area for microbial attachment, thereby increasing the treatment efficiency. Also, stone media tends to clog easily. Figure 1 shows a bed of stone media (1a) and typical plastic media (1b) commonly used in trickling filters. Whereas stone media constitutes more conventional (”old”) trickling filter technology, the more efficient plastic media has started to replaced stone media in recent years and latter is generally seen as “new technology”.



(a) Stone Media (McKinney, 1962) (b) Plastic Media (Munters®, 2000)

Figure 1. Typical biological filter material used in trickling filters.

On the surface of the media a slimy layer consisting of many different types of microorganisms establishes itself. This layer is called a biological film and contains protozoa, algae and various types of aerobic, anoxic and anaerobic microorganisms. Aerobic organisms are found in the outer portion of the film. Deeper into the biological film, the oxygen becomes depleted resulting first in anoxic conditions and, still deeper into the layer, in anaerobic conditions prevailing. As the wastewater passes through the filter, nutrients and oxygen diffuse into the biological film and are consumed/taken up by aerobic microorganisms, whereas microbial by-products and carbon dioxide diffuse out of the film into the liquid. Anoxic and anaerobic microorganisms do not require molecular oxygen and therefore proliferate from the microbial by-products released by the aerobic microorganisms and other nutrients in the wastewater that were not used by the aerobic microorganisms. This principle is shown schematically in Figure 2.

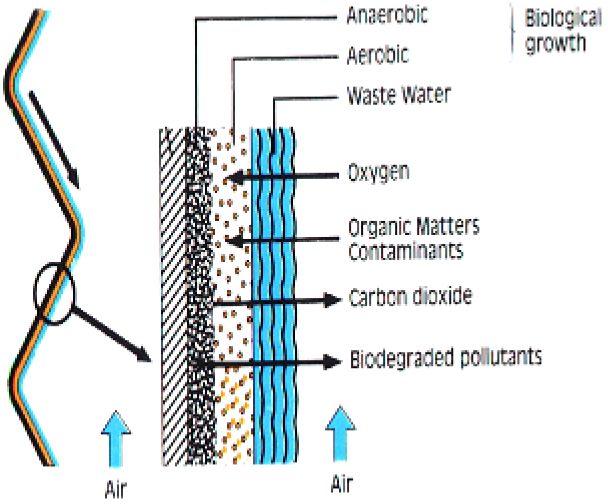


Figure 2. Biological activity on biofilter media (Munters®, 2000).

3.1.2 Oxygen absorption.

Oxygen is introduced into the wastewater and biofilm from the air. This is achieved when the wastewater is sprayed over the media by rotary distributor arms or nozzles. Additionally, there is a natural draft established inside the filter bed, which results in oxygen diffusing from the air into the water that percolates down the media and so reaches the biological film. The natural draft can be from the top to the bottom or *vice versa* and often shows seasonal directional changes as the outside air temperature changes.

3.1.3 Organic material removal.

The incoming wastewater contains organic matter, which is removed by the various microorganisms as the liquid flows over the media. Organic matter removal by the filter is a function of the microorganisms present, organic concentration applied, the media characteristics such as surface area and depth, retention of the liquid in the filter and temperature.

In generalized terms, the equation for microbial growth (in the presence of microorganisms) can be written as:

Carbon source + Energy + H^+-acceptor + Nutrients → Microorganisms + By/end-products

The main biochemical reactions taking place during organic material removal contained in sewage are shown below.

- Anaerobic digestion:

  This process takes place strictly with the exclusion of molecular oxygen, i.e. no dissolved oxygen may be present!. Two major groups of bacteria are responsible for stabilising the organic matter: One group is responsible for the hydrolysis of the solids with major end products being soluble, short chain fatty acids and stable, insoluble residue, similar to humus. The other group is responsible for the conversion of the fatty acids formed, to methane gas and carbon dioxide. The process is controlled by the methane-forming bacteria, which are very pH and temperature sensitive. If the pH drops to below 6,0 methane formation ceases and the digestion process comes to a standstill.

  Anaerobic digestion typically prevails in the first, anaerobic sludge beds of a pond system, septic tanks, primary clarifiers, humus tanks and anaerobic digesters.

- Aerobic carbonaceous material breakdown (eg carbohydrates, glucose):

  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (+ energy)

  This process needs molecular oxygen, e.g. dissolved oxygen obtained from the air that is introduced into the wastewater during aeration. The energy that has been liberated is used for bacterial growth to form new cells.

- Protein breakdown:

  Protein → amino acids → ammonia → nitrite → nitrate

- Ammonia removal/nitrification:

  $NH_4^+ + 1\,½O_2 \rightarrow NO_2^- + H_2O + 2H^+$

  $NO_2^- + ½O_2 \rightarrow NO_3^-$

  The above reactions take place with the aid of autotrophic bacteria, called nitrifiers, in two sequential steps: Ammonia is converted to nitrite by *Nitrosomonas* while *Nitrobacter* then converts the nitrite to nitrate, and both reactions need oxygen to take place.

- Denitrification (Anoxic Process):

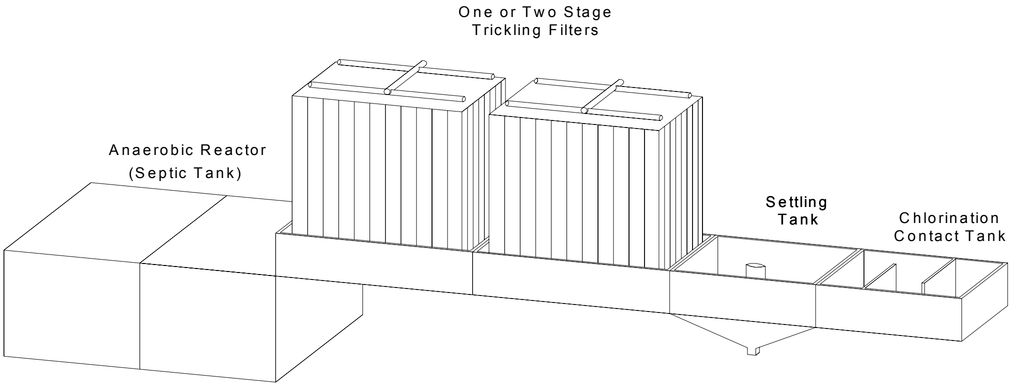
  In the absence of molecular (dissolved) oxygen the nitrate ion that is formed in the above reaction, is converted to nitrogen gas by microorganisms undergoing anaerobic respiration. This process takes place when aerobic microorganisms are introduced to an anaerobic effluent to obtain to an anoxic environment, typically by recycling activated sludge back to a section of the anaerobic reactor. The microorganisms then convert the nitrates (and nitrites) to nitrogen yet do not allow sulphates to be converted to sulphides. This process is used for nitrogen-removal in biological reactors.

3.2 APPLICATION

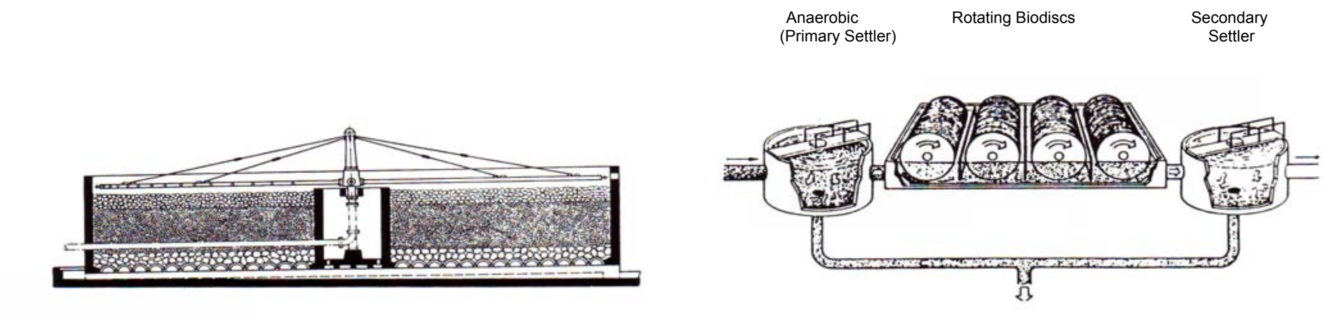
Biofilters are widely used throughout Namibia for sewage treatment, from small-scale trickling filters for lodges, medium sized systems for airports, schools and small communities and large-scale systems for large towns such as Windhoek. There are mainly two types of attached-growth systems in use, Rotating Biological Contactors and Trickling Filters (see Figure 3) .

A complete sewage treatment system based on attached-growth technology typically consists of:

- Primary treatment. This is an anaerobic stage, which can consist of a septic tank, anaerobic pond or primary (=anaerobic) clarifier;
- An aerobic stage, typically rotating biodiscs or a trickling filter. Latter can be one or two stages, whereby the one-stage trickling filter would incorporate carbonaceous material removal and nitrification in one tower, whereas separate towers would be provided for carbonaceous material removal and nitrification in a two-stage process;
- Settling tank for secondary clarification, which is used to separate the microbial mass from the clear effluent;
- Disinfection, whereby chlorine in various forms (gas, liquid, pills) is used primarily as disinfectant throughout Namibia.



(a) New-generation Trickling Filter Plant (small-scale) (ASE, 2000)



(b) Tricking Filter with Stone Media (c) Rotating Biodisc Treatment Plant

Figure 3. Most commonly employed attached-growth systems (Quasim, 1983).

New generation trickling filters are nowadays designed to achieve the same quality of final effluent that can be obtained from activated sludge processes. This also includes biological N and P-removal and is achieved by recycling part of the sludge and trickling filter effluent streams.

When considering advanced biological treatment for sewage treatment, attached–growth systems constitute the most simple and therefore most appropriate systems for local conditions.

Advantages. Attached-growth systems have several advantages, which include:

- Simple to operate – no highly skilled operators necessary;
- No complicated mechanical equipment employed - pumps and geared motors (bigger plants only) are the only advanced equipment employed that can break;
- Need little supervision – no significant adjustments to equipment can be made;
- Low running costs – compared to activated sludge processes they only need approx. one third of the energy requirement;
- Can tolerate shock loads – where recycle streams are employed, the daily peaks (fluctuations in flow and load) are greatly smoothened;
- Can tolerate and recover more easily from toxic loads – the short contact time of the wastewater with the slime layer will result in only the outer layer of microorganisms being poisoned and killed. The inner layer stays in tact and growth will pick up fast after the toxic incident;
- Low sludge production – they only produce approx. 1/3 of the volume of sludge produced in an activated sludge reactor.
- Small footprint. Compared to pond systems, attach-growth systems only need approx. 1/20 of the area;
- Can be placed closer to inhabited areas. Whereas pond systems should not be placed closer than 500 m from the closest inhabitants, properly operated and maintained attached-growth systems do not produce undue nuisance constituents and can be placed within 50 m of the closest inhabited area.

Disadvantages. It is especially the old generation trickling filter that has been associated with the following disadvantages:

- Odours. The stone-media type trickling filter often becomes clogged in the upper layer due to sludge build-up caused by clogging of the voids in-between the stones. This results in, what is commonly called “ponding”, which is a build-up of effluent on the surface of the filters and results in strong, unpleasant odours. If this occurs, the top ca 1/3 of the media must be removed and manually cleaned, which is a labour intensive task. Where plastic media is used, the arrangement/form of the media is such that channels are formed that ensure the sludge can slide off to the bottom of the tank so that no clogging can take place inside the media any more.
- Fly breeding. The stone media often gives shelter for flies to breed in. Also, if the effluent is applied with distributor arms, latter do not wet/spray the media constantly and thus do not hold off flies. New generation trickling filters generally employ nozzles that constantly spray the effluent over the media, thereby fending off flies.
- Large filters structures required. Due to the small specific area of stone media, quite large structures filled with stones have been built in the past. However, the plastic media that is nowadays employed has been developed with a much higher specific surface (= wetable) area, which now require considerably smaller units being built.

As mentioned above, new-generation trickling filters that are packed with plastic media have overcome the general shortcomings of the old-generation, stone filled trickling filter. The technology in this field has advanced to a stage where trickling filters can now also produce a final effluent similar in quality than an activated sludge plant.

4. TRICKLING FILTER SYSTEM DESIGN

New generation attached-growth systems are fairly specialised and the design thereof should be left to a specialist in the wastewater field. In the below section, only the trickling filter will be discussed, general design considerations given and some specific operating characteristics of the media employed will be dealt with. It should definitely not be seen as a designer's manual for attached growth systems.

Before considering providing a new trickling filter system for a community, suitability of the general set-up and area intended for such a system should be thoroughly assessed. Fairly accurate figures for the design loading (volume and COD/BOD) should then be established and general climatic conditions of the area intended should be obtained before any design can be considered. For the latter, future needs should also be taken into account, e.g. population growth, influx etc.

4.1 SITE SELECTION

Most important considerations for selecting a suitable site include:

- Location. If anaerobic ponds will be employed as primary (anaerobic) treatment process they may not be built closer than 500 m from the nearest residential area, but ideally, this distance should be increased to 1,0 km. If a septic tank or primary clarifier is employed as primary treatment process this distance may be reduced but is subject to approval by DWAF.
- Ground water table. Areas with high water tables should be avoided - groundwater pollution from seepage or overflows must always be regarded as a high possibility when wastewater treatment plants are employed.
- Wind. In areas where excessive winds do occur, the superstructure (that houses the media) should be designed to take such windloads. The minimum wind speed used for design purposes should be not less than 80 km/h.
- Population served. Biological filtration systems may be employed for any number of people, but must surely be considered as an advanced treatment system if the ultimate load of a community exceed 5 000 PE (population equivalents) or 800 kℓ/d.
- No power lines. Care must be taken that no power lines, above or below ground, cross the area envisaged for the treatment system system.

4.2 INFORMATION REQUIRED FOR DESIGN

The following minimum, reliable design information must be available for designing attached-growth systems:

- Sewage volume discharged (ADWF and WWF – Section 2.2.1);
- Sewage strength (organic load – COD/BOD – Section 2.2.2);
- Climatic conditions (temperature, wind, rainfall, evaporation rate, sunshine).

4.3 TRICKLING FILTER MEDIA

Crushed stone was widely employed as media for trickling filters. This has been replaced in the new-generation trickling filters with plastic media, which again consists of many different types and designs. Many trickling filters in Namibia still employ stone media and therefore, both types of media will now be discussed.

4.3.1 Stone media (Quasim, 1983).

Media. Large, hard gravel, generally 25 to 75 mm in size, is used. It should be uniform in size to produce maximum void spaces for adequate ventilation and proper drainage and sufficiently hard to not disintegrate with time. Larger media gives less surface area for microorganisms to grow on, but has better drainage and ventilation characteristics.

Bed depth. The minimum bed depth should not be below 1,8 m to allow sufficient contact time for the wastewater with the media. Maximum bed depth should not be more than 3,6 m to ensure proper washing out of the microorganisms (sludge).

4.3.2 Plastic Media (Munters®, 2000)

Media. New-generation trickling filters are generally packed with two different types of plastic media:

- Low specific attachment surface area at the top. The top section (or first stage) of a trickling filter sees the highest organic load (= lots of food for microorganisms), resulting in microorganisms establishing on the media that are mainly responsible for carbonaceous material removal. These are "heavy" and fast growing microorganisms and therefore need to be hosted on a media with low surface area to prevent clogging thereof. The media used for this section has a specific surface area of 80 to 100 m^2/m^3. Whereas the (dry) media without microbial growth weighs ca 30 kg/m^3, the weight thereof increases to ca 350 kg/m^3 when in full operation.
- High specific attachment surface area at the bottom. The bottom section (or second stage) of the trickling filter sees much less organic material and therefore much less microbial activity takes place here and the main microorganisms present are nitrifying bacteria. Latter are slow growers and light and therefore a plastic material with larger specific area can be used without danger of clogging. The media used for this section has a specific surface area of 150 to 200 m^2/m^3.

Bed depth. The minimum bed depth, even when artificial media is used, should not be below 1,8 m to allow sufficient contact time for the wastewater with the media. However, maximum bed depths can be much larger than with stone media because the specific design of the media allows self-cleaning, thereby preventing clogging. The only constraint becomes the weight of the media in operation. To prevent the media from collapsing under its own weight, a maximum heights of 6 m as a single stage is used. However multiple stage trickling filters can be designed and heights of 24 m have been built in India.

Table 2 summarizes main parameters and operating characteristics of trickling filters for different media types for an average wastewater temperature in the range of 13 – 30°C.

Table 2: Typical design parameters and operating characteristics of biofilters.

Characteristics	**Low Rate Media**		**High Rate Media**	
	Rock*	Plastic**	Rock*	Plastic**
Depth, m	1,8 – 3,6	1,8 – 6,0	1- 2,5	3 - 12
Specific Surface, m^2/m^3	40 - 70	80 - 100	40 - 70	150 - 200
Porosity/Voids	0,45 - 0.55	> 0,97	0,45 - 0,55	> 0,97
Hydraulic loading rate [$m^3/m^2.d$]	0,5 - 3,0	1,0 – 5,0	8 - 30	10 - 50
Organic loading rate, [kg $BOD_5/m^3.d$]	0,1 - 0,4	0,5 - 0,9	0,4 - 1,8	0,6 - 3,0
Recirculation ratio	0	1- 4	1- 4	1- 4
Washing-off (“sloughing”)	Intermittent	Continuous	Continuous	Continuous
Main Application	Carbonaceous material removal		Pre/roughing filtration, Nitrification	
Effluent BOD [mg/ℓ]	< 25	< 10	≥ 30	≥ 30
Effluent SS [mg/ℓ]]	< 25	< 25	≥ 30	≥ 30

* Reference - McKinney, 1962
**Reference – Munters®, 2000

4.4 BIOLOGICAL FILTRATION SYTEMS COMMONLY EMPLOYED

After screening, the raw sewage passes through an anaerobic, primary sedimentation stage, followed by aerobic, biological filtration, removal of the microbial mass by sedimentation and disinfection of the final effluent. Sludge is withdrawn and discharged to sludge drying beds from the anaerobic stage as well as the settler. Recycle streams, to increase the efficiency of the biological filter and to obtain biological N- and P-removal, are also often employed. The following schematic drawings depict different types of biological filter systems that are commonly employed in Namibia:

4.4.1 Single-stage filtration, once through system

These are mostly gravity flow systems with one trickling filter and without recycle. Such systems are mainly employed for carbonaceous material removal with little or no nitrification taking place. The schematics of such a system are depicted in Figure 4.

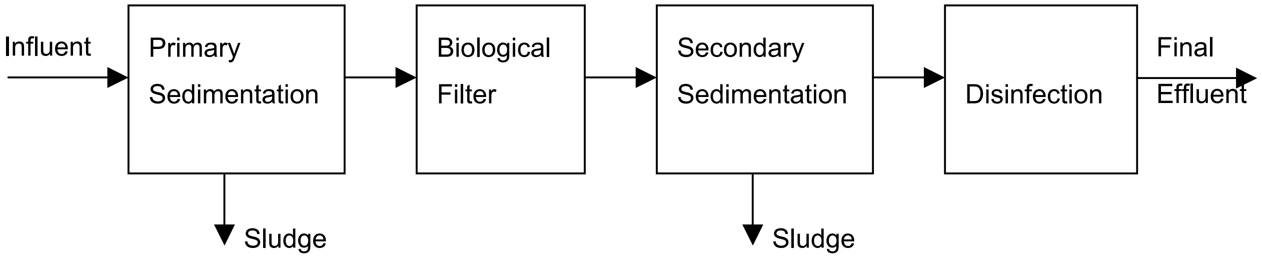


Figure 4. Single-stage (once through) biological filtration

4.4.2 Double-stage filtration, once through system

Also mostly gravity flow systems, but with two trickling filters in series. One finds that the first filter mainly removes carbonaceous material, whereas good nitrification is obtained in the second trickling filter. The schematics of this system are depicted in Figure 5.

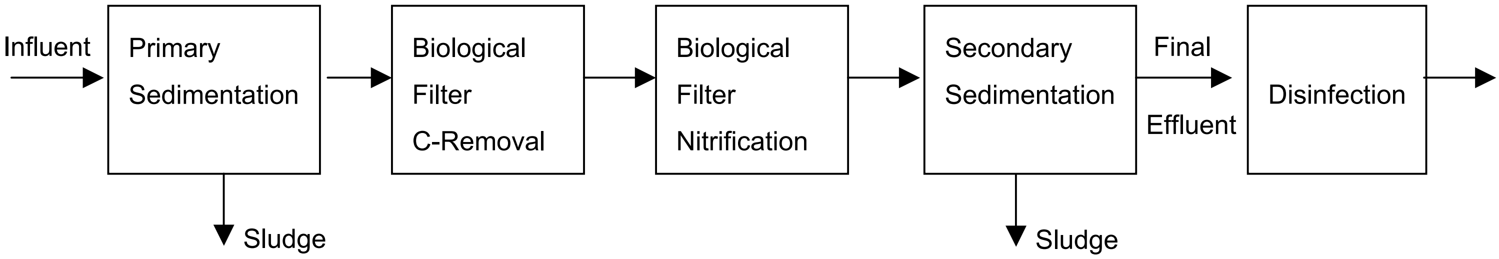


Figure 5. Double-stage (once through) biological filtration

4.4.3 Single-stage filtration with recycle

Efficiencies of trickling filter systems are vastly improved by employing recycling over the trickling filter itself. Biological N-removal can also be obtained when sludge from the secondary clarifier is returned back to the anaerobic reactor. The schematics of such a system are depicted in Figure 6.

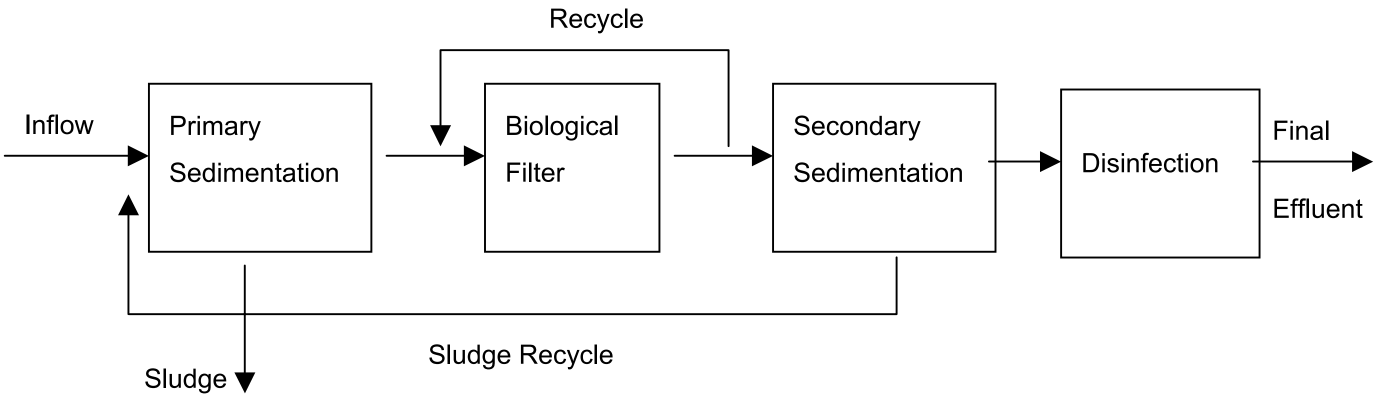


Figure 6. Single-stage biological filtration with internal recycle

4.4.4 Double-stage filtration with recycle

Double-stage biological filters with an internal recycle over each filter are usually employed to deal with high-strength organic loads as discharged by industries. The schematics of such a system are depicted in Figure 7.

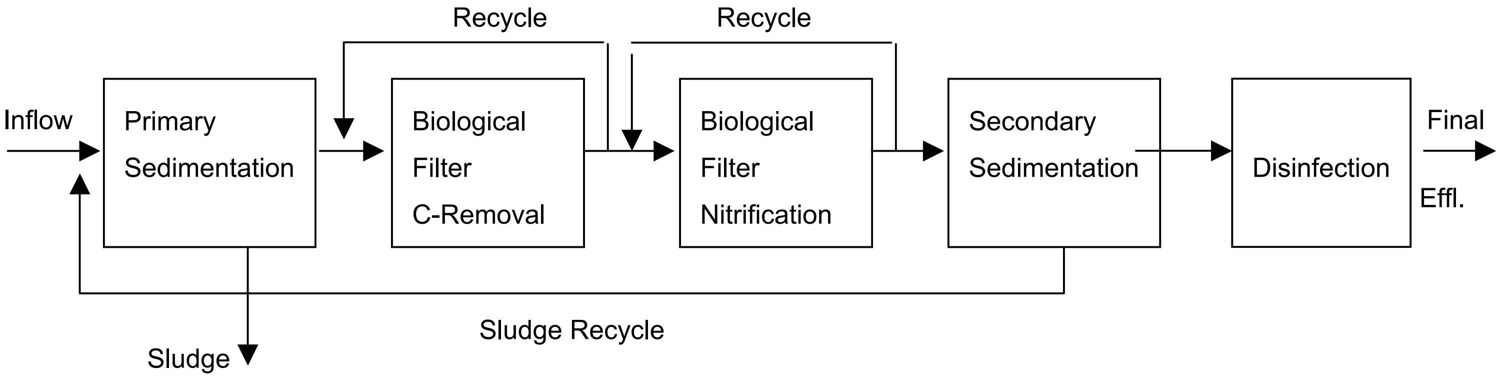


Figure 7. Double-stage biological filtration with internal recycle

4.5 TREATMENT PLANT PERFORMANCE EMPLOYING TRICKLING FILTERS

A properly designed and well-managed sewage treatment plant that employs grid removal, primary (anaerobic) treatment, trickling filters, settling and disinfection will produce a final effluent that can be reused for irrigation of lawns, fodder crops and fruit and vegetables not eaten raw. However, a reuse permit from DWAF is required. Typical effluent qualities that can be obtained at the different stages of treatment in a treatment plant employing trickling filter technology are shown in Table 3.

Table 3: Typical effluent quality parameters at different stages of treatment in a trickling filter plant (revised from Horan, 1990)

	BOD (mg/ℓ)	COD (mg/ℓ)	TKN (mg/ℓ)	NH_3-N (mg/ℓ)	NO_2/NO_3 (mg/ℓ)	Alkalinity (mg/ℓ)	pH
Raw Sewage	300	600	45	25	-	220	7,1
After Primary Treatment	150	300	45	25	-	220	7,4
After Trickling Filter	10	150	25	8	20	50	6,9
After Secondary Settler	10	70	15	5	15	50	6,9
Maturation Pond Effluent	5	60	15	2	10	100	7,5

5. PERIPHERALS/ASSOCIATED ITEMS TO BE PROVIDED

Consideration should be given to the following items that form part of the overall treatment plant to ensure that the system can be easily maintained and be kept in a properly functioning condition:

5.1 SCREENS AND GRIT CHANNELS

Bar screens and detritus channels, correctly sized and designed, should be installed in front of the primary treatment reactor, e.g. the septic tank or primary settler. The screens must be cleaned daily and utmost care should be exercised that no rags, plastic bags or other large objects are discharged into the process downstream. Screenings should be discarded to the municipal dumping site or buried underneath a layer of soil not less than 800 mm deep at a site specifically set aside for this purpose.

5.2 MEASURING DEVICES

A V-Notch weir to measure flow at the inlet to a plant must be provided. Flow discharge data is useful for load calculations and to indicate when a system needs extending.

5.3 DISINFECTION

Only if the final water conforms to the General Standard as per the Water Resources Management Act, 2004 (Act No. 24 of 2004), is it allowed to be discharged into the environment. Since water is a scarce commodity in Namibia, reuse thereof is strongly encouraged. A reuse permit obtainable from DWAF is required for this purpose.

Before discharge, the final effluent must be disinfected, even if it does not come in direct contact with humans. For proper disinfection, chlorine or any other recognised disinfection method may be applied. Chlorine comes commercially in various forms:

- As a gas (but liquefied under pressure) in steel cylinders;
- In liquid form (containers) as sodium hypochlorite;
- In solid form, commonly distributed as chlorine pills or granules (e.g. HTH).

If chlorine use added, this chemical must be added to the final effluent and be allowed to react for at least 20 minutes to kill potentially harmful microorganisms. This is done in a chlorination tank, properly designed to ensure the chlorine is spread evenly throughout the complete volume of water. Sufficient chlorine must be added to obtain and maintain a free chlorine residual above 0,3 mg Cl_2/ℓ, measured 20 minutes after application and at peak flows.

5.4 FENCING

The treatment plant must be completely fenced in to prevent people and animals entering the area and ample notices must be provided to warn and keep people out of this area. As a minimum, a “jakkalsproef” fence at least 1,8 m high with double-gate to allow access for trucks must be provided. The gate must be kept properly locked.

No animals or people are allowed to swim in any of the process treatment units!

5.5 FINAL DISCHARGE

Final effluent from a biological treatment plant can be discharged into a dry riverbed or into a sub-surface percolation system. It is also encouraged to re-use the final effluent from biological filtration plants for gardening and/or limited agricultural application, provided the final water quality confirms to the General Standard. However, a permit from DWAF is required to reuse such water.

6. OPERATION AND MAINTENANCE

Regular maintenance should be carried out to maintain a high standard of effluent, to avoid nuisance problems and to avoid a rapid physical decline of the infrastructure.

Although highly-skilled manpower is not required for routine operation and maintenance, a skilled (trained) supervisor must be employed by the owner of the plant. Regular cleaning, periodic sampling and checking certain items should be attended to conscientiously. It is also important to check the inflow to the plant and reassess the number of users (population growth) once a year to ensure that the system does not become overloaded. These points will be further highlighted in this section.

Depending on the size of the system there should be one or two semi-skilled, trained operators based at the plant and the supervisor should visit the plant at least once a week to ensure that all mechanical items are still running.

Where a new biological treatment plant with a capacity of 1 000 kl/d or larger is constructed, the owner must include for a one-year operation and maintenance period during which the wastewater treatment contractor must provide an operator full-time on site to train the owner’s personnel to properly operate and maintain this plant.

6.1 DAILY INSPECTION

At least one semi-skilled operator with specific training in wastewater treatment must be present full-time on site to report on and do the following maintenance functions (as a minimum):

- Clean the screens and detritus channels. Discard to municipal waste site or bury all screenings, detritus and extraneous material in prepared pits;
- Record the inflow once a day if a flowmeter has been installed;
- Check if all motors and pumps are running – repair/replace immediately if broken;
- Look out for any leakages – fix pipes etc immediately;
- Keep the area inside the fence and up to 1 m outside of the fence free from any vegetation;
- Check that all overflows are clear;
- Check fence and repair immediately if damaged;
- Check disinfection system;
  - Check that disinfection system is properly functioning;
  - Check that disinfection chemicals are sufficient;
  - Check dosing rates are sufficient for proper disinfection;
- Check other mechanical items employed are functioning, e.g. pumps, valves etc.

6.2 PERIODIC/INFREQUENT INSPECTION

A skilled supervisor should visit the treatment works at least once per week to ensure that the , operator is on site and looking after the plant at al times. Additionally, a wastewater treatment specialist or consultant needs to be employed to visit the sewage treatment plant and especially to assess the trickling filter system at least twice per year to carry out certain inspections and tests and to advise the owner of changes in the operation or additional, periodic maintenance to be undertaken. This will include (as a minimum):

- Check, assess and report on the performance of the operator(s);
- Check, assess and report on the general condition of the site (e.g. neat and tidy, fence and gate properly maintained, etc.;

- Note and raise any concern regarding possible leaks or situation that may lead to contamination of the groundwater or endanger human and/or animals;
- Check flow meter readings (check condition of flow meter);
- Check sludge level in anaerobic tank (e.g. septic tank if employed) – advise client to clean if required;
- Collect a set of composite samples of the inflow and final effluent (minimum requirement) – also refer to Section 8 below. Ideally, each unit process should be sampled and analysed to assess its operation and to build up a database;
- Observations of smell and colour should be noted. This can serve as check for possible overloading of plant or malfunctioning of the trickling filter;
- Measurements of pH and dissolved oxygen to confirm the observations indicated by smell and colour;
- Check, assess and report on dosing rates, condition of dosing equipment, performance etc of the disinfection system;
- Check, assess and report on all other mechanical equipment installed;
- Compile a report of all findings. This report should be made available on request to DWAF;

7. SAMPLING AND ANALYSES

DWAF will specify the required frequency of sampling in the permit conditions. Where no frequency is specified, samples must be taken once every six months and analysed for the tests required by DWAF. These analyses must be undertaken by an approved, recognised laboratory for wastewater analyses.

The load of the wastewater entering the treatment plant during a normal day varies significantly, both with regards to volume and organic load, depending on the domestic activities at that time. Therefore a composite sample over 24 hours of the inflow should ideally be taken. This is not a simple process and should rather be left to be undertaken by an expert in the wastewater treatment field. However, grab samples can be used as an indication.

Grab samples at the final outflow of the plant will give a good indication of the overall performance achieved by the plant. The following procedure describes how to take grab samples and store them for analyses by a suitable laboratory:

- Collect samples at the inlet (as inflow) or outlet (as outflow) of a specific unit process;
- Put on surgical gloves;
- Take a sealed, clean 2 ℓ plastic bottle, fill and rinse three times with the wastewater that is to be sampled;
- If microbial indicators need to be established, sterilised glass bottles should be used (obtainable from the lab that will later do these analyses);
- Fill sampling bottle completely and seal (put on cap) while still under water/while bottle overflows;
- Mark or label each bottle immediately. The labels on the bottles should clearly indicate the name of the plant, owner, exact sampling point/place (GPS-reading?), date, time and the parameters that should be analysed for;
- Store sample bottles at or below 4°C and deliver them to the laboratory to be analysed. This can be achieved by storing the sample bottles in a refrigerator and transporting them inside a cooler bag/box with ice cubes;
- Samples must reach the laboratory within 24 hours, otherwise the bottles must be preserved with sulphuric acid (H_2SO_4) or nitric acid (HNO_3) and be kept at cool temperatures;
- If microbial indicators need to be established, the samples must reach the lab within 24 hours from sampling.

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