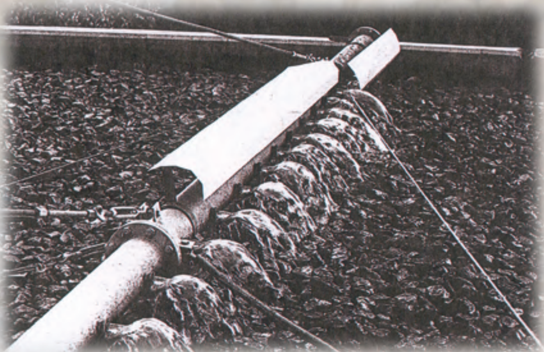
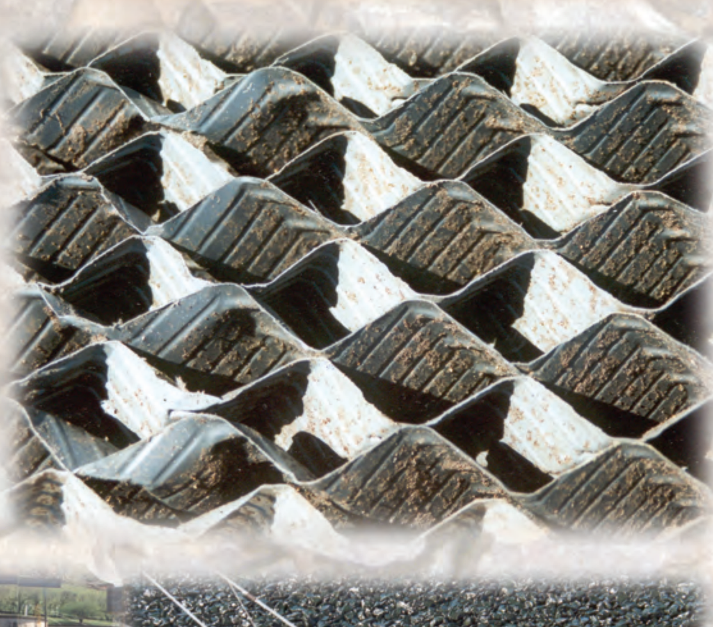
Guidelines for the Application of Natural Stone Trickling Filters

With Some Reference to Synthetic Media Trickling Filters





Water Research Commission

TT 178/02

Guidelines for the Application of Natural Stone Trickling Filters

With Some Reference to Synthetic Media Trickling Filters

Report to the
Water Research Commission

by

Wates, Meiring & Barnard (Pty) Ltd

WRC Report No: TT 178/02

Obtainable from:

Water Research Commission
Private Bag X03
Gezina
0031

The publication of this report emanates from a project entitled: *Investigation into optimisation of high rate biological filtration for wastewater treatment* (WRC Project No. K5/929)

ISBN No. 1-86845-852-0

Printed in the Republic of South Africa

Executive Summary

Trickling filters are applied in many domestic and industrial wastewater treatment plants in Southern Africa. Trickling filtration technology is still evolving and this document provides current information on the design, operation and maintenance of filters.

TRICKLING FILTER TECHNOLOGY APPLICATIONS

The guidelines for applications of natural stone trickling filters (with some reference to synthetic media trickling filters) are based on research and wastewater treatment plant surveys conducted over the last five (5) years. The Water Research Commission funded the construction and operation of a pilot trickling filter installation at Baviaanspoort Wastewater Treatment Plant. The results of the pilot investigation were reported in the Water Research Commission report 569/1/99 titled "*High Rate Biological Filtration*". Several surveys of full scale trickling filters were conducted to assess the practical application of the technology.

The research and surveys were conducted in Southern Africa, but the guidelines can be applied to any trickling filtration facility treating mainly domestic sewage in warm to temperate climates.

Trickling filters can be utilised in many different applications, either as a stand alone treatment technology or in combination with other treatment technologies such as oxidation ponds and activated sludge processes. Wastewater treatment process configurations could include dual stage trickling filters, polishing nitrification filters, trickling filter/solids contact process, trickling filter/activated sludge process, Petro^{TM} process and side-stream nitrification trickling filters.

HYDRODYNAMIC ASPECTS

The hydrodynamic aspects of trickling filter design and operation dictate the proper distribution of flow, effective retention time in the filter and adequate wetting of the filter media. Hydraulic retention time is a key parameter in filter performance. Tracer studies and liquid hold-up tests are useful in understanding the effective filter retention time. Proper flow distribution requires attention to hydraulic head losses, centrifugal force effects and rotational speed. Poor flow distribution is responsible for many under-performing filter installations. Effective filter flushing to remove excess biomass and to promote good ventilation is receiving more attention by designers and operators.

VENTILATION AND OXYGEN TRANSFER

Many trickling filters fail to satisfy process requirements due to inadequate oxygen transfer. Two generic air ventilation designs are considered:

- Natural draft systems, based on the temperature differential between the percolating wastewater and ambient air, which are appropriate for most low organic loading applications.

- Forced draft systems can be installed with low power demand fans and are a requirement for high organic loading applications.

TRICKLING FILTER MEDIA

Trickling filter media must be selected with care and international standards are available for generic media types including:

- Natural stone media, commonly applied in Southern Africa.

- Random or structured synthetic media.

Natural stone and synthetic media must be selected based on considerations of size, specific area (m^2/m^3), void space, shape, strength and durability. Long-term strength of synthetic media requires special consideration during design.

CARBON REMOVAL

Trickling filters are very effective compared to other treatment technology for carbon (BOD/COD) removal. Filters can be operated over a range of organic loading rates to achieve BOD/COD removal including:

- High rate trickling filters operated at organic loading rates of > 2 000g COD/m^3-day to achieve 40 – 60 % COD removal.

- Low rate trickling filters operated at organic loading rates of < 750g COD/m^3-day to simultaneous carbon/nitrogen removal.

Many different empirical and quasi-deterministic models have been developed to simulate trickling filter performance in terms of carbon removal. These models can reliably predict filter performance for domestic wastewater, but require field verification for industrial applications.

NITROGEN REMOVAL

Trickling filters are also successfully applied to remove nitrogen and can be operated to nitrify (oxidise ammonia) and denitrify (reduce nitrate). Nitrification filters require operation at low organic loading rates to allow the nitrifier bacteria to successfully compete with the faster growing Heterotrophic bacteria. Adequate oxygen supply is critical to effective nitrification. Nitrification performance is also impacted by the ammonia concentration levels (especially when a low effluent ammonia, < 3 - 4 mg/ℓ NH_3-N is required), residual alkalinity to stabilise the pH, and depth of filters (potential for patchy nitrifier growth at the bottom of the filter).

PRACTICAL APPLICATION

Practical construction of trickling filters requires attention to many detailed aspects such as filter walls, floors and underdrains. Filter support systems are especially important to synthetic filter media. The rotary distribution system can be hydraulically driven or mechanically driven. The latter drive system is becoming increasingly popular due to better operational control of the filter.

The capital cost of trickling filters will depend on the local site geotechnical conditions, construction technique, mechanical equipment and selection of filter media. The typical total installed cost ranges between R300 to R700 per m^3 of filter volume.

The operation and maintenance cost depends on personnel, chemical dosing, electrical power consumption, equipment maintenance, monitoring and management costs.

The guidelines are aimed at technical practitioners in the wastewater treatment field including managers, operators, designers and researchers.

Acknowledgements

The research in this report emanated from a project funded by the Water Research Commission entitled:

"GUIDELINES FOR THE APPLICATION OF NATURAL STONE TRICKLING FILTERS (WITH SOME REFERENCE TO SYNTHETIC MEDIA TRICKLING FILTERS)"

Steering Committee Members

Representative	Institution
Dr G Offringa	Water Research Commission
Mr GN Steenveld	Water Research Commission
Mr P Smit	Water Research Commission
Mrs J A Venter	Water Research Commission
Dr AM van Niekerk	Wates, Meiring & Barnard
Mr G Rudert	Wates, Meiring & Barnard
Mr MB Haw	East London Municipality
Mr JHB Joubert	East Rand Water Care Company, ERWAT
Mr GB Saayman	Tshwane Metropolitan Council
Mr CM Howarth	Durban Metropolitan Council Water Services
Mr AL Batchelor	CSIR Environmental
Prof PD Rose	Department of Bio Chemistry & Microbiology - Rhodes University
Mr PJC Wagener	Bloemfontein Transitional Local Council

The financing of the project by the Water Research Commission and the contribution of the members of the Steering Committee are acknowledged.

Case Studies

This project was only possible with the co-operation of various individuals and institutions. The authors therefore wish to record their sincere thanks to the following:

- *Riverview Wastewater Treatment Plant in Witbank*
- *Oberholzer Wastewater Treatment Plant in Carletonville*
- *Gammams Wastewater Treatment Plant in Windhoek*
- *Baviaanspoort Wastewater Treatment Plant in Pretoria*

Acknowledgement is due to Mr Du Toit Loots, former Superintendent of the Sewage Treatment Works, Carletonville Local Municipality for sharing his practical expertise on the distribution of water over Trickling Filters as related to their performance.

A special thanks to Mr Z A Paszek, former Senior Engineer, Department of Local Government Housing, Kwa Zulu Natal Provincial Administration, for his contribution towards process understanding of Intermediate-Rate Full-scale, Rock Trickling Filters.

Table of Contents

Executive Summary .... **i-iii**

Acknowledgements .... **iv**

Table of Contents .... **v-vi**

List of Tables .... **vii**

List of Figures .... **viii**

List of Acronyms .... **ix-x**

Glossary of Terms .... **xi**

CHAPTER 1 .... **1**

1. INTRODUCTION **1**

CHAPTER 2 .... **3**

2 APPLICATION OF TRICKLING FILTER TREATMENT TECHNOLOGY **3**
- 2.1 Wastewater Characterisation 3
- 2.2 Pre-Treatment 5
- 2.3 Treatment Process Configuration 6

CHAPTER 3 .... **13**

3 HYDRODYNAMIC ASPECTS **13**
- 3.1 Hydraulic Loading 13
- 3.2 Retention Time 14
- 3.3 Flow Distribution 18
- 3.4 Hydraulic Design of Flow Distributors 24
- 3.5 Flushing of Filters 27
- 3.6 Media Wetting Efficiency 31

CHAPTER 4 .... **33**

4 VENTILATION AND OXYGEN TRANSFER **33**
- 4.1 Oxygen Requirements 33
- 4.2 Natural Draft Ventilation 35
- 4.3 Pressure Drop 37
- 4.4 Forced Draft Ventilation 38

CHAPTER 5 .... **40**

5 TRICKLING FILTER MEDIA **40**
- 5.1 Type of Stone Media 40
- 5.2 Characterisation of Stone Media 40
- 5.3 Media Depth 42
- 5.4 Synthetic Filter Media 43

CHAPTER 6 .... **44**

6 CARBON REMOVAL **44**
- 6.1 Carbon Loading Rate 44
- 6.2 Modelling of Carbon Removal 45
- 6.3 Clarification 51
- 6.4 Temperature Effects 53
- 6.5 Solids Production 53

CHAPTER 7 56

7 NITROGEN REMOVAL 56
7.1 Species of Nitrogen 56
7.2 Environmental Factors Impacting Nitrogen Removal 59
7.3 Nitrogen Removal (Nitrification) in the Presence of Carbon Compounds 60
7.4 Dedicated Nitrification Filters 61

CHAPTER 8 64

8 PRACTICAL APPLICATION ASPECTS 64
8.1 Filter Shape 64
8.2 Walls Construction 64
8.3 Filter Media Supports 65
8.4 Underdrains 66
8.5 Filter Media Strength 66
8.6 Distribution Devices 67
8.7 Dosing Siphons 68

CHAPTER 9 69

9 ECONOMICS OF TRICKLING FILTRATION 69
9.1 Capital Investment 69
9.2 Operating and Maintenance Costs 70

REFERENCES 71

LIST OF TABLES

Table 1 : Wastewater Treatment Technologies Applied in South Africa ... 1

Table 3.3 (a) : Trickling Filter Distribution Arms at Two Different Rotational Speeds ... 21
Table 3.3 (b) : Hydrodynamic Condition in Different Speed Performance ... 22
Table 3.5 : Recommended SK Values of Different Organic Loading Rates ... 29

Table 5.2 (a) : Size Distribution of Trickling Filter Stone (% Passing) ... 41
Table 5.2 (b) : Physical Properties of Natural Stone Media ... 42
Table 5.4 : Typical Synthetic Filter Media Properties ... 43

Table 6.2 : Empirical Rate Constant Values ... 46

LIST OF FIGURES

Figure 2.2 (a) : Ponding and Poor Drainage of the Filter 6
Figure 2.2 (b) : Exposure of Iron Sulphide Solids Blocking the Filter Media 6
Figure 2.3 (a) : Conventional Trickling Filtration Process 7
Figure 2.3 (b) : Dual Stage Trickling Filtration Process 8
Figure 2.3 (c) : Polishing Nitrification Trickling Filter Process 8
Figure 2.3 (d) : Trickling Filter/Solids Contact Treatment Process 9
Figure 2.3 (e) : Trickling Filter/Activated Sludge Process 10
Figure 2.3 (f) : Trickling Filter Integrated with Ponds (Petro^{TM}) 11
Figure 2.3 (g) : Side Stream Nitrification Trickling Filtration Process 12

Figure 3.1 : Trickling Filter Definition Diagram 14
Figure 3.2 (a) : Retention Time as a Function of Hydraulic Loading Rate 15
Figure 3.2 (b) : Wastewater Hold-Up as a Function of Hydraulic Loading Rate 17
Figure 3.2 (c) : Results of Tracer Study on Riverview WWTP Trickling Filters 18
Figure 3.3 (a) : Flow Distribution to Trickling Filter 19
Figure 3.3 (b) : Trough on Radial Wire to Measure the Flow Distribution 20
Figure 3.3 (c) : Radial Troughs Across the Filter Media 20
Figure 3.3 (d) : Oberholzer WWTP – Flow Distribution Investigation 21
Figure 3.3 (e) : Tracer Study Results on Slow/Fast Trickling Filters 22
Figure 3.3 (f) : Spilling Across the Centre Distribution Well 23
Figure 3.3 (g) : Poor Splash Plate Design and Inadequate Feed Spreading 23
Figure 3.3 (h) : Loss of Water from Distributor End Cap 24
Figure 3.3 (i) : Good Filter Feed Distribution Pays Dividends 24
Figure 3.4 : Filter Distribution Definition Diagram 25
Figure 3.5 (a) : Spülkraft as a Function of the Number of Distributor Arms 28
Figure 3.5 (b) : Adjustable Braker Plates 30
Figure 3.5 (c) : Verulam Trickling Filters with Installed Breaker Plates 30

Figure 4.2 (a) : Air Density as Function of Temperature and Humidity (Atmospheric Pressure = 760 mmHg) 35
Figure 4.2 (b) : Natural Downdraft Ventilation 36
Figure 4.2 (c) : Updraft Situation – Wastewater Temperature Higher than Ambient Air Temperature 36

Figure 6.2 (a) : Empirical Rate Constant as Function of Filter Depth and Feed COD Concentration 47
Figure 6.2 (b) : Organic Removal Performance of a Low Rate Trickling Filter 49
Figure 6.2 (c) : Organic Removal Performance of a High Rate Trickling Filter 50
Figure 6.2 (d) : Impact of Recirculation on COD Removal 50
Figure 6.2 (e) : Impact of Stone Media Size on Trickling Filter Performance 51
Figure 6.5 : Biomass Distribution in Synthetic Media Filter 55

Figure 7.1 (a) : Conversion of Nitrogen Species in Trickling Filters 57
Figure 7.1 (b) : Nitrogen Conversion in a Trickling Filter 58
Figure 7.3 : Nitrification Efficiency as a Function of Organic Loading Rate 61

Figure 8.2 (a) : Filter Walls Constructed of Cut Sandstone Blocks 65
Figure 8.2 (b) : Filter Wall Construction Using Interlocking Blocks 65
Figure 8.6 : Typical Centre Column Mechanical Drive Installation 67

LIST OF ACRONYMS

a	Part area
A	Cross-sectional area of a filter (m^2)
A	Distribution pipe area (m^2)
A_s	Total stone media surface area (m^2/m^3)
A_w	Wetted stone media surface area (m^2/m^3)
AFR	Air flow required (m^3/min)
C	Conversion constant
COD_e	Filter effluent COD concentration (mg/ℓ)
COD_i	Feed wastewater COD concentration (mg/ℓ)
D	Distribution pipe diameter(m)
D	Filter depth (m)
D_a	Reference trickling filter height (m)
D_x	Site specific trickling filter height (m)
E	Media effectiveness factor
f	Friction coefficient
f	Non-degradable volatile solids fraction
FF	Flushing force (N)
f_{un}	Un-biodegradable nitrogen fraction
f_{up}	Fraction of un-biodegradable particulate COD
f_{us}	Fraction of un-biodegradable soluble COD
g	Gravitational acceleration (m/s^2)
h	Head loss (m)
h	Total energy head
h_c	Head caused by centrifugal forces (m)
h_f	Final total energy head (at distribution pipe end)
HLR	Hydraulic loading rate (m^3/m^2-day)
h_o	Initial total energy head (at centre column)
h_{rs}	Static pressure at radial position r (m)
h_R	Total head loss over pipe length R (m)
IS_o	Feed inert solids concentration (mg/ℓ)
K_{20}	Reaction rate at 20°C
K	Empirical constant
K_a	Reference empirical constant
K_n	Nitrification rate (gN/m^3-day)
K_{no}	Nitrification rate at 20°C (gN/m^3-day)
K_{nt}	Nitrification rate at temperature, T (gN/m^3-day)
$K_{o,max}$	Maximum oxygen supply rate (g/m^2-day)
K_t	Reaction rate at temperature, T (g/m^2-day)
K_x	Site specific empirical constant
M_o	Oxygen content of air (kg/kg)
n	Empirical constant
N	Bulk ammonia nitrogen concentration ($mgNH_3$-N/ℓ)
N	Filter resistance

N	Number of holes
N	Rotational speed (rpm)
N	Number of arms
N_k	Half saturation concentration (mgℓ NH_3-N)
OHU	Operation hold-up (m^3/m^3 of filter volume)
OLR	Organic loading rate (gCOD/m^2-d)
P	Solids production (mg/ℓ)
ΔP	Pressure differential (Pa)
ΔP_a	Air flow head loss (m)
P_a	Ambient air density (kg/m^3)
P_f	Filter air density (kg/m^3)
q	Discharge at a port
Q	Feed wastewater flow rate (m^3/day)
Q	Flow discharge over filter area bounded by radius r
Q_o	Total flow discharge via distributor arm (m^3/day)
Q_r	Recycle flow rate (m^3/day)
Q_h	Flow per hole (m^3/day)
r	Radial position on filter surface (m)
R	Trickling filter radius (m)
R	Recycle ratio (R/Q)
S_a	Reference feed BOD/COD concentration (mg/ℓ)
S_e	Effluent BOD/COD concentration (mg/ℓ)
SK	Flushing rate (mm/pass of arm)
S_o	Feed BOD/COD concentration (mg/ℓ)
S_o^1	Blended feed BOD/COD concentration (mg/ℓ)
S_x	Site specific BOD/COD concentration (mg/ℓ)
T	Retention time (mins.)
T_1	Inlet air temperature (^oC)
T_2	Exhaust air temperature (^oC)
T_a	Ambient temperature (^oC)
T_m	Natural log mean air temperature (^oC)
V	Flow velocity (m/s)
V	Filter media volume (m^3)
VOLR	Volumetric organic loading rate (gCOD/m^3-day)
VORR	Volumetric organic removal rate (gCOD/m^3-day)
V_r	Velocity in the distribution pipe at any radial position r (m/sec)
VS_o	Feed volatile solids concentration (mg/ℓ)
w	Angular velocity
W	Wetting efficiency
W_o	Reference wetting efficiency
Y_n	Biosolids yield (kg VSS/kg COD removed)
ρ	Density (kg/m^3)
η	Oxygen transfer efficiency
$\theta_{c,n}$	Arrhenius coefficient

GLOSSARY OF TERMS

ADF	Alternating Double Filtration
ALK	Alkalinity
BNR	Biological Oxygen Demand
BOD_5	Biological Oxygen Demand (5 days)
BOD	Biological Nutrient Removal
BS	British Standard
$CaCO_3$	Calcium Carbonate
$CBOD_5$	Carbonaceous Biological Oxygen Demand (5 days)
CBOD	Carbonaceous Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DSS	Dispersed Suspended Solids
DWAF	Department of Water Affairs and Forestry
FeS	Iron Sulphide
FSS	Flocculated Suspended Solids
H_2S	Hydrogen Sulphide
IWA	International Water Association
N	Nitrogen
NO_3-N	Nitrate Nitrogen
NH_3-N	Ammonia Nitrogen
O&M	Operating and Maintenance
OD_c	Carbonaceous Oxygen Demand
OD_n	Nitrogenous Oxygen Demand
PVC	Poly-Vinyl-Chloride
SC	Solids Contact
TS	Total Solids
TSS	Total Suspended Solids
TKN	Total Kjeldahl Nitrogen
VSS	Volatile Suspended Solids
WEF	World Environment Federation
WWTP	Wastewater Treatment Plant

Chapter 1

1 INTRODUCTION

Trickling filters are finding increasing application in different wastewater treatment configurations ranging from high rate carbon removal pre-treatment units to low rate nitrogen removal polishing units. The traditional trickling filter process involving combined carbon and nitrogen removal has become less attractive for a number of economic and technical reasons. These reasons include:

- Relatively high capital cost for conventional trickling filters compared to other treatment technologies.

- Poor process reliability with respect to nitrogen removal, especially in the colder winter months. This constraint may become even more significant in view of recent proposals to revise and introduce more stringent discharge standards.

- Little process control and poor flexibility to adjust to changing flow and load conditions.

Many South African treatment plants (DWAF, 1999), however, still have trickling filters as reflected by the results of a recent national survey of approximately 1 100 plants, conducted to investigate the range of treatment technologies applied in South Africa (DWAF, 1999):

Table 1: Wastewater Treatment Technologies applied in South Africa

Activated sludge	35%
Trickling filters	23%
Activated sludge and trickling filter combinations	6%
Pond systems	16%
Other technologies	20%

Process developments related to trickling filters continue and trickling filters are utilised in new and innovative ways. The integration of trickling filters with other treatment processes such as oxidation ponds and activated sludge also opens up new opportunities for application. Rock trickling filters can also be upgraded by installation of synthetic media to increase treatment capacity.

This document provides guidelines for the design and operation of trickling filters in existing and new installations. Many existing installations can be optimised by the implementation of recent developments related to trickling filters. The document draws on international and local research and development work.

The guidelines were also based on previous research work on high rate trickling filter undertaken at the Baviaanspoort Test Facility. Full scale plant case studies conducted at the Riverview (Witbank) plant, Oberholzer (Carletonville) plant, Gammams (Windhoek) plant and Velddrift plant were also consulted in the preparation of these guidelines. The guidelines are therefore based on experience and practices in Southern Africa, but will apply to any trickling filter facility operated under similar flow, load and climatic conditions.

The guidelines are aimed at technical practitioners in the wastewater treatment field including managers, operators, designers and researchers.

Chapter 2

2 APPLICATION OF TRICKLING FILTER TREATMENT TECHNOLOGY

Natural stone trickling filters may find a wide range of application in the treatment of wastewater. The application may be as the main, stand-alone treatment process or integrated with other fixed film or suspended culture processes.

Generically the potential range of applications can be categorized as follows :

- High rate carbon removal filters with a typical organic loading rate of 1000 to 6000 $gCOD/m^3$ - day.
- Combined carbon and nitrogen removal filters with typical organic loading rate of 250 to 750 $gCOD/m^3$ - day and nitrogen loading rate of 0,2 – 1,0 gN/m^2 - day.
- Tertiary nitrification filters for the polishing of ammonia rich secondary effluents with nitrogen loading rates of 0,5 to 2 gN/m^2 - day.

2.1 Wastewater Characterisation

Proper characterisation of the wastewater is important in predicting and understanding trickling filter performance.

Wastewater Solids

The wastewater solids must be defined in terms of TSS and VSS concentrations. It is also useful to have information about the solids particle size distribution. The passage of colloidal and small, especially inorganic solids, through a trickling filter is still poorly understood. Effective solids captured in the downstream clarification step are very important in achieving effective overall plant performance.

Wastewater Carbon

The carbon content of wastewater is typically expressed in terms of Biochemical Oxygen Demand (BOD_5 , $CBOD_5$) and Chemical Oxygen Demand (COD). The fraction of the carbon content in the following components is also important in predicting filter performance:

- Soluble, non-biodegradable fraction
- Soluble, biodegradable fraction
- Particulate, biodegradable fraction

The soluble, non-biodegradable carbon will pass through the filter without modification and report in the filter effluent. The particulate, non-biodegradable carbon may be partially captured in the biomass and separated in the downstream solids separation step. Trickling filters are very effective in removing soluble, biodegradable carbon. This fraction is metabolised by the biofilm and converted to biomass and CO_2. The particulate carbon fraction is only partially metabolised and the removal of this fraction is dependent on incorporation/capture in the sloughed biomass and downstream solids separation.

Historically, trickling filter loading and performance were described in terms of BOD measurements. This could result in over/under prediction of the actual carbon load on the trickling filter, since the COD : BOD ratio can vary between 1.5 : 1 and 3.0 : 1, even in wastewater not containing toxic or inhibitory compounds.

The recent trend is towards expressing trickling filter performance in terms of COD and characterisation of COD into the different fractions outlined above.

Wastewater Nitrogen

The nitrogen contained in wastewater should be defined in terms of:

- Organic nitrogen
- Ammonia nitrogen
- Nitrate/nitrite nitrogen

Trickling filters are very effective in rapid hydrolysis of organic nitrogen into ammonia. If the wastewater nitrogen content is only characterized in terms of ammonia nitrogen, it will not account for the ammonia generated by organic nitrogen hydrolysis. This may result in an underestimate of the true nitrogen load on the trickling filter. Substantial organic nitrogen concentrations may be present in fresh domestic wastewater, food and beverage industrial effluent, tannery effluents, abattoir effluent, fish processing effluents etc.

Recycle flows to the trickling filters may contain nitrate/nitrite nitrogen. This may be valuable source of bound oxygen, which will be released by denitrification and will then relieve the oxygenation requirements of the filter.

Wastewater Stability

The wastewater chemical stability (buffer capacity) is typically characterised by the total carbonate alkalinity. Trickling filters perform best in the near-neutral pH range of 6.5 to 8.0. This requires a minimum residual alkalinity of 50 – 70 mg/ℓ as $CaCO_3$.

Conversion of nitrogen species changes the wastewater alkalinity substantially as reflected below:

- Ammonia oxidation (nitrification) consumes alkalinity:
  - 7.2 mg $CaCO_3$/mg NH_3-N oxidised

- Organic nitrogen hydrolysis releases alkalinity:
  + 3.6 mg $CaCO_3$/mg Organic N hydrolysed

- Nitrate/nitrite reduction (denitrification releases alkalinity):
  + 3.6 mg $CaCO_3$/mg NO_3 – N reduced

2.2 Pre-Treatment

The pre-treatment of wastewater upstream of the trickling filter is essential for a number of reasons:

- Removal of solids which could block the filter media

- Removal of large bulky items which could accumulate as an unsightly layer on top of the filter

- Protection of the filter against very high hydraulic and organic loads

- Protection of the filter against toxic and inhibitory compounds, which will impact detrimentally on the biogrowth in the filter.

The minimum pre-treatment requirement upstream of a trickling filter is primary clarification. It is desirable, but not essential to screen the filter feed, typically down to 3 mm size.

Flow and load equalisation are also desirable, since they provide more even and steady operating conditions to the filter. Many trickling filtration installations are overloaded during daytime and underloaded during night time operations. It may be more economical to install flow/load equalisation followed by a smaller but optimised trickling filter installation.

Septic tanks and anaerobic ponds are also appropriate pre-treatment processes for trickling filters. This form of pre-treatment can provide adequate solids separation as well as a degree of flow/load equalisation. The filter feed from septic tanks and/or anaerobic ponds may, however, have a low redox potential with elevated sulphide concentrations. Sulphide, especially in the undissociated H_2S form, may be toxic to heterotrophic bacteria in trickling filters. Allowance must then be made for the pre-oxidation of the sulphide (occurs naturally by microbial action of organisms such as *Beggiatoa* and related species), to protect the trickling filter. Septic feed streams may also contain fine colloidal solids, which will wash through the filter. Effective capture and removal of such solids depends on effective flocculation and solids clarification downstream of the filter.

Figures 2.2 (a) and **2.2 (b)** show the results of poor pretreatment. In this specific case, the filter feed flow was high in iron sulphide (FeS) solids, which clogged the filter media and caused ponding.

Figure 2.2 (a) : Ponding and Poor Drainage of the Filter

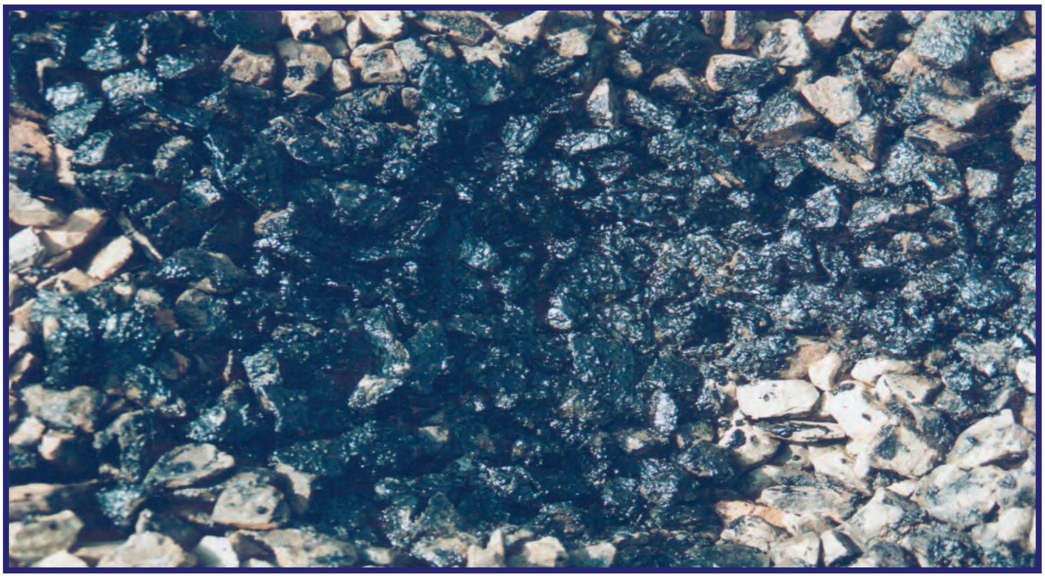


Figure 2.2(b): Exposure of Iron Sulphide Solids Blocking the Filter Media

2.3 Treatment Process Configuration

Conventional Trickling Filters. The conventional trickling filtration process as commonly applied in Southern Africa involves a treatment chain, which includes:

- Primary Clarification for solids removal
- Trickling filtration for both carbon and nitrogen removal

- Humus clarification for biosolids removal

The feed wastewater is pre-clarified in a primary clarifier. Primary effluent is then fed to the trickling filters. The trickling filters are operated at relatively low loading rates to achieve both BOD/COD removal and to oxidise ammonia to nitrate. The biosolids sloughed from the trickling filter are captured in the humus clarifier, which is the final treatment step, before disinfection and discharge. **Figure 2.3 (a)** shows the conventional trickling filter treatment process.

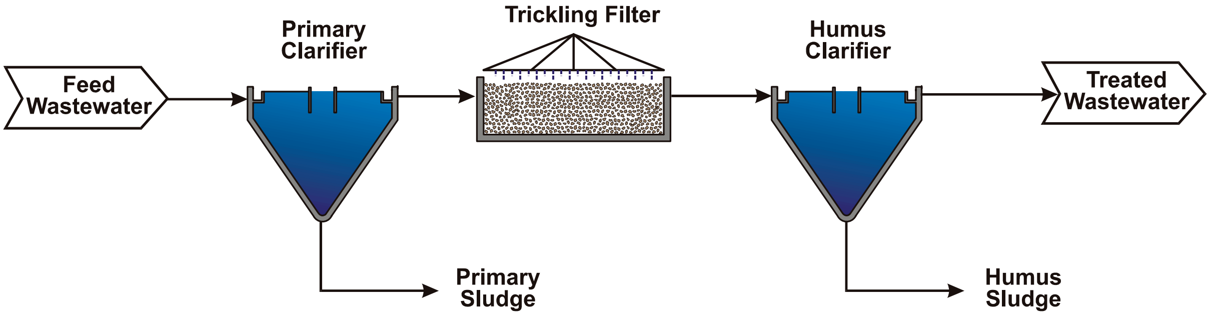


Figure 2.3 (a): Conventional Trickling Filtration Process

Dual Stage Trickling Filters. The dual stage trickling filtration process incorporates separate trickling filters, which are typically operated in a series configuration. The main treatment process train includes the following unit treatment process:

- Primary clarification
- Primary trickling filter
- Secondary trickling filter
- Humus clarifiers

Solids removal is achieved in the primary clarifier. The primary effluent is then fed to the primary trickling filter, which is operated primarily for carbon removal. The primary trickling filter effluent is then treated in a secondary trickling filter, which is operated for ammonia oxidation. The biomass from the trickling filters is removed in the final humus clarifiers. The dual stage process could also incorporate an intermediate clarification step depending on the solids production from the primary trickling filter. A variation of the Dual Stage Trickling Filtration process is to alternate the trickling filters. This process variation is referred to as the Alternating Double Filtration (ADF) process configuration. This mode of operation has been successful in optimising filter performance, specifically in terms of underloading and elimination of patchy biofilm growth on the secondary trickling filter. The frequency of switching depends on the specific plant operating conditions and this requires plant specific optimisation. **Figure 2.3 (b)** shows the dual stage trickling filter process configuration.

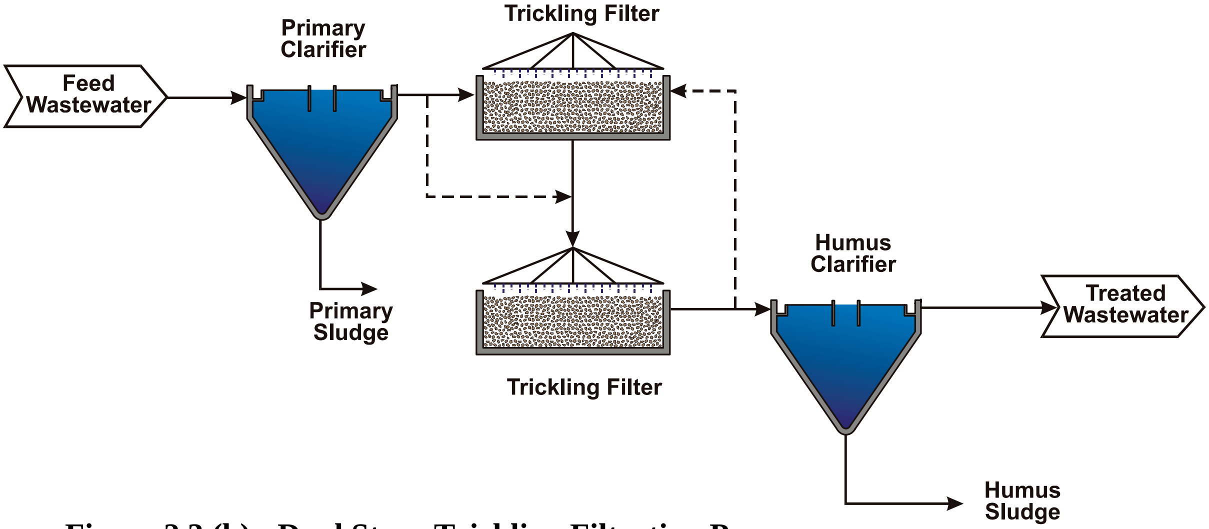


Figure 2.3 (b) : Dual Stage Trickling Filtration Process

Polishing Nitrification Filters. Trickling filters can also be utilised for polishing treatment specifically to achieve ammonia oxidation on a bio-treated effluent. The typical process configuration includes the following:

- Primary biological reactor and associated biofilter to achieve BOD/COD and TSS removal.
- Nitrification filter for ammonia oxidation.

The primary biological reactor can either be attached, such as a trickling filter, or suspended, such as an activated sludge process for the removal of carbon and solids from the feed wastewater. The product from the first stage biological reactor would still contain elevated ammonia concentrations. This water is then fed to a nitrification filter for polishing treatment in terms of ammonia oxidation. Due to the very low nitrifier bacterial solids yield the polished nitrified effluent does not need another solids separation clarifier step. For example, in a trickling filter which oxidises 25 mg/ℓ NH_3-N, an additional 3 to 4 mg/ℓ of TSS is added to the wastewater flow. The process configuration is shown in **Figure 2.3(c)**

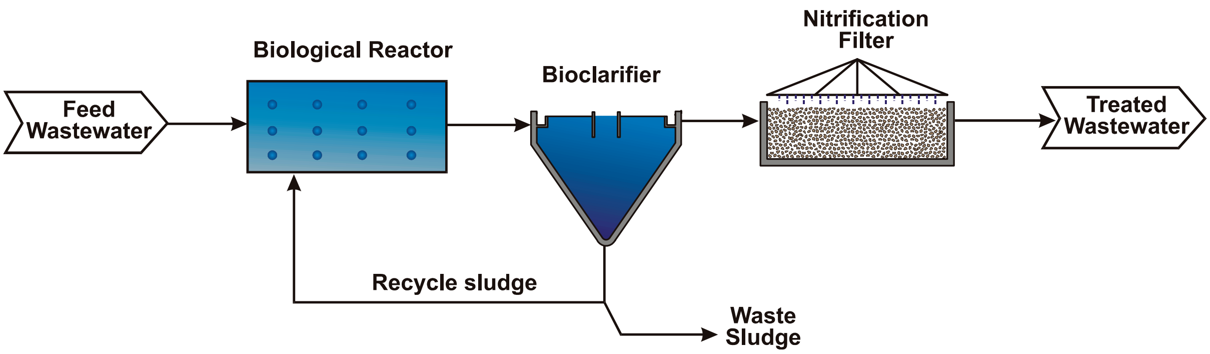


Figure 2.3 (c) : Polishing Nitrification Trickling Filter Process

Trickling Filter/Solids Contact Process. The trickling filter/solids contact process is a variation of the conventional trickling filtration process. As special feature is incorporated into the treatment process, to enhance the flocculation and settlement of biosolids sloughed from the trickling filter. The typical process train contains the following components:

- Primary clarifier for solids removal
- Trickling filter for carbon and nitrogen removal
- Solids contact box to achieve affective flocculation of the sloughed biosolids
- Thickening clarifier for solids separation

The component of the TS/SC process is very partial recycling of the secondary clarifier underflow. This recycle enters a solid contact box where it is blended with the trickling filter effluent. The combined streams are gently aerated to satisfy the process oxygen requirement and to achieve re-flocculation of the biosolids fluffed from the trickling filter. The secondary clarifier is usually designed with a flocculating centre valve to achieve a high quality secondary effluent. **Figure 2.3 (d)** shows the process configuration.

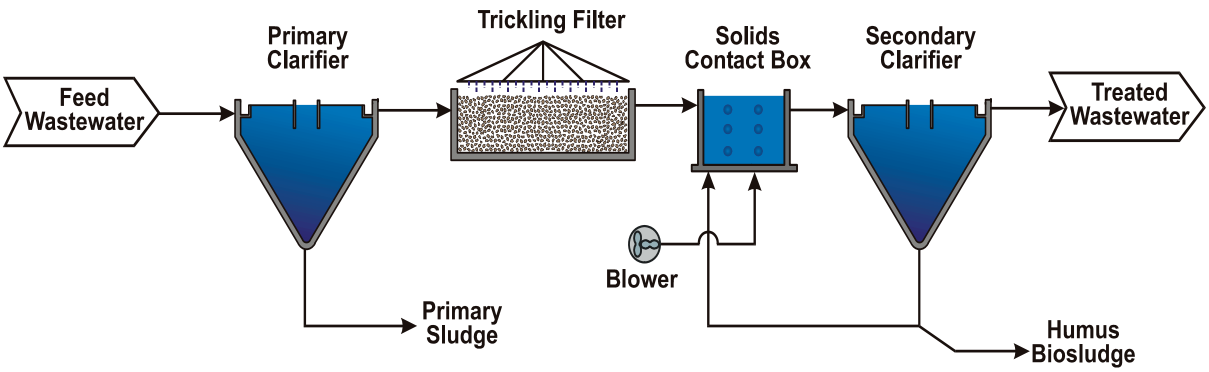


Figure 2.3 (d): Trickling Filter/Solids Contact Treatment Process

Trickling Filter/Activated Sludge Process. This process combines a trickling filter as a primary biological treatment step followed by activated sludge as a polishing step. The treatment process train incorporates the following unit treatment processes:

- Primary clarification
- Roughening trickling filter
- Polishing activated sludge with associated secondary clarifier

The primary role of the trickling filter is to remove the bulk of the carbonaceous compound as affected in the BOD/COD content of the primary effluent. The activated sludge process then polishes this pre-treated effluent, specifically in terms of removal of residual BOD/COD and removal of nitrogen. The activated sludge process may require some supplemental carbon if a high degree of nitrogen removal is required. This is achieved by a bypass stream around the roughening trickling filter. **Figure 2.3 (e)** shows the integrated trickling filter activated sludge process configuration

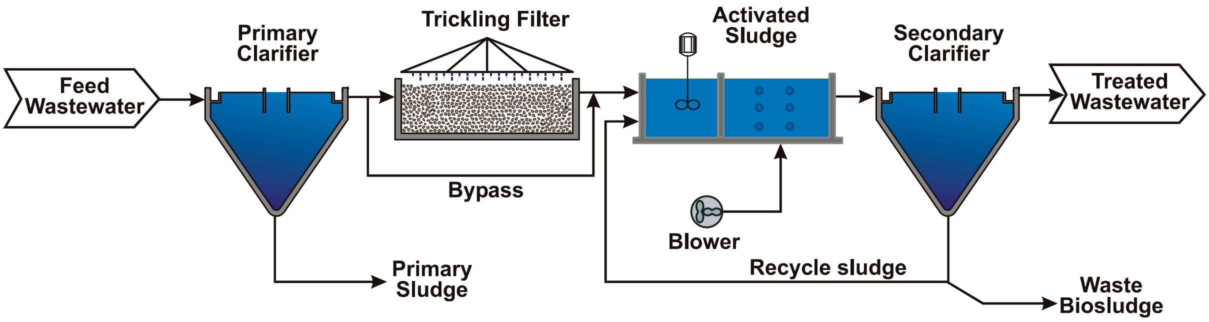


Figure 2.3 (e): Trickling Filter/Activated Sludge Process

Trickling Filters Integrated with Pond Systems (Petro^{TM}). This process integrates upstream treatment in a pond system followed by polishing in a conventional trickling filter and humus clarifier process. Several variations of this process are available, but the main components as reflected in the patented Petro^{TM} process include:

- Anaerobic pond for removal of dark suspended solids and partial BOD/COD breakdown.
- Recycle to an oxidation pond for further BOD/COD and ammonia removal
- Trickling filter to polish the pond effluent, specifically in terms of removal of residual BOD/COD and ammonia oxidation.
- Humus clarifier for final solids separation.

The upstream combination of anaerobic and oxidation ponds provides an effective means of removing the bulk of the BOD/COD compounds as well as ensuring partial nitrogen removal. The process configuration also allows for the introduction of an aerated algal rich stream to the top layers of the anaerobic pond, which assists in odour control. The downstream trickling filter is primarily designed for ammonia oxidation and has achieved effective nitrification. The final humus clarifier achieves solid separation before the treated effluent is discharged. **Figure 2.3 (f)** shows the patented Petro^{TM} process, which reflects the process flow scheme for the integrated pond and trickling filter process.

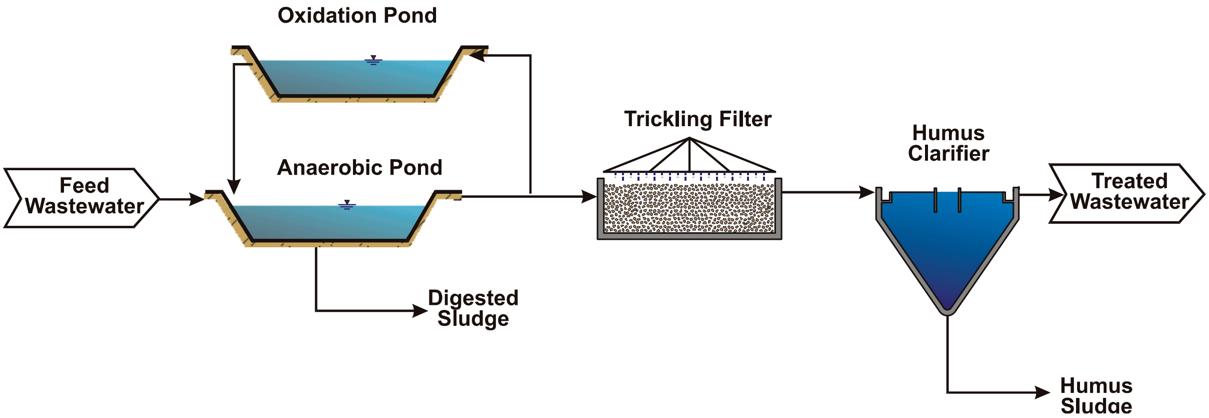


Figure 2.3 (f): Trickling Filter Integrated with Ponds (Petro™)

Side-Stream Nitrification Trickling Filters Process. This process is a new variation, which combines biological nutrient removal (BNR) activated sludge and a side stream nitrification trickling filter. The process relies on the main stream removal of BOD/COD and phosphate in the main stream activated sludge process with ammonia oxidation on a side stream trickling filter. The main treatment process components include:

- Anaerobic reactor, which stimulates the release of phosphate in the presence of bio-degradable compounds.
- The mix liquor is then separated in an intermediate clarifier. The clarified overflow is set to side stream process.
- A side stream trickling filter is incorporated to achieve ammonia oxidation. The nitrified trickling filter is returned to the mainstream activated sludge process.
- The intermediate clarifier underflow and the nitrified trickling filter effluent are combined in an anoxic reactor. This allows the denitrification process to continue.
- Final BOD/COD breakdown and oxidation of any residual ammonia is achieved in the aerobic reactor.
- Final solids separation is achieved in a secondary clarifier from which the activated sludge is recycled back to the BNR activated sludge process.

This process has been developed on pilot scale and is currently considered for full-scale application in Southern Africa. **Figure 2.3 (g)** shows a schematic of the side-stream nitrification trickling filtration process.

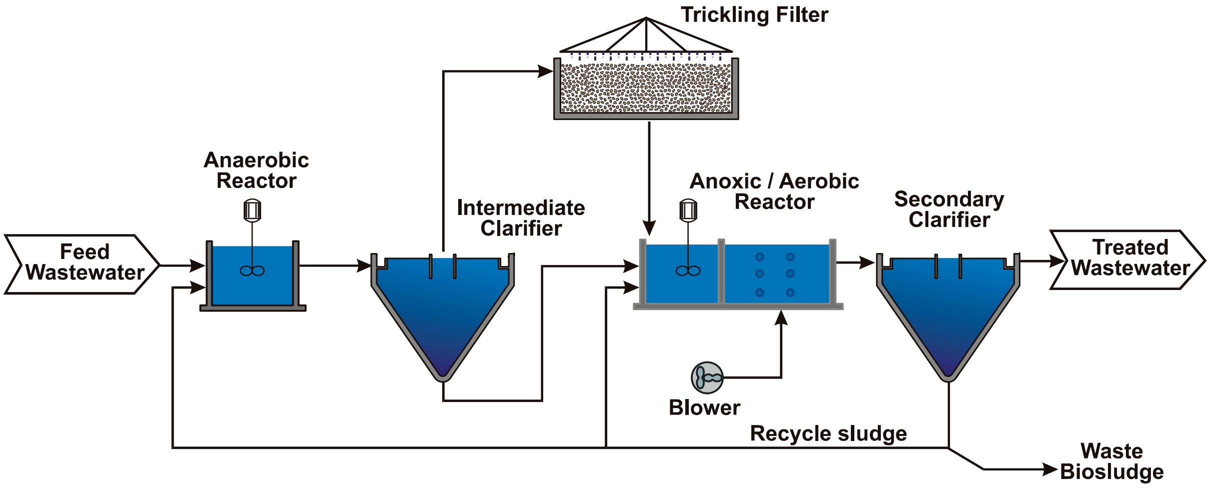


Figure 2.3 (g): Side Stream Nitrification Trickling Filtration Process

The many different treatment process applications for trickling filters require understanding of the technology at a fundamental and applied level.

Chapter 3

3 HYDRODYNAMIC ASPECTS

The hydrodynamic aspects of a trickling filter are very complex and difficult to model due to the intricate and variable flow paths through the filter. The different flow patterns manifest in a range of residence times which are determined by :

- Flow distribution across the filter top
- Filter media size and type
- Wetting of filter media
- Collection of filter effluent

The hydrodynamic aspects are important for effective filter performance due to the influence in terms of wastewater and biofilm contact opportunity, effective contact time between wastewater and biofilm, diffusion of substrate into the biofilm and the export of reaction products from the biofilm.

3.1 Hydraulic Loading

The hydraulic loading on a trickling filter is typically defined as a surface loading rate :

$$HLR = (Q + Qr)/A \qquad 3.1.1$$

where HLR = hydraulic loading rate (m^3/m^2-day)
Q = feed wastewater flow rate (m^3/day)
Qr = recycle flow rate (m^3/day)
A = cross-sectional area of filter (m^2)

The definition of the trickling filter process configuration is shown in **Figure 3.1**.

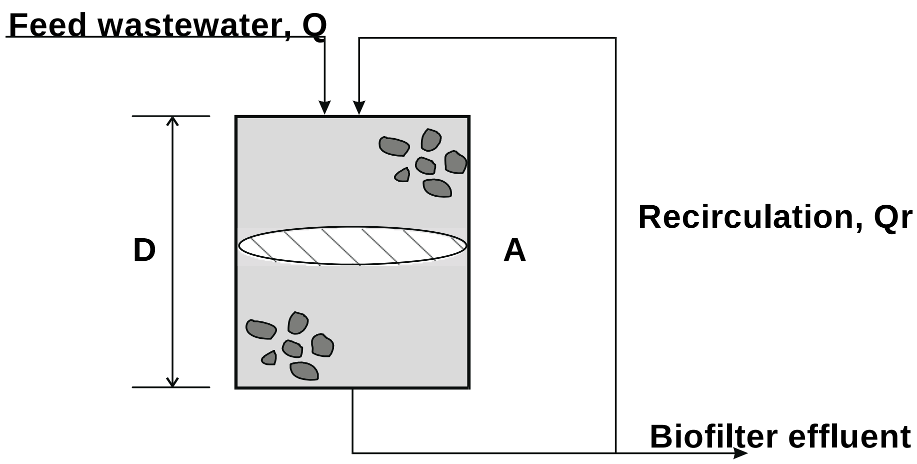


Figure 3.1 Trickling Filter Definition Diagram

The hydraulic loading rate tends to increase as the organic loading rate increases for trickling filters without a re-circulation flow. The organic loading rate (as defined in Section 6 of this document) is directly related to feed wastewater flow rate and feed wastewater carbon concentration. For trickling filters without re-circulation, both the hydraulic loading rate and the organic loading rate increase as the feed wastewater flow increases. Conversely, the hydraulic loading rate can be increased without a significant change in organic loading rate by introducing recirculation across the trickling filter.

The hydraulic loading rate impacts on the filter retention time, effective wetting of the filter media and a range of related process variables, which influence filter performance.

3.2 Retention Time

The surface hydraulic load and filter depth determine the retention time in a trickling filter. Retention time is also influenced by the properties of the filter media, specifically the media size and shape. The classical relationship is:

$$T = K.D/[(Q+Q_r)/A]^n \quad \text{3.2.1}$$

where

T	=	retention time (mins)
K and n	=	empirical constants
D	=	filter depth (m)
Q	=	filter feed flow rate (m^3/min)
Q_r	=	recycle flow rate (m^3/min)
A	=	filter cross-sectional area (m^2)

The empirical constants , K and n are sensitive to the type of filter media, the biogrowth on the filter media and operation of the filter. The empirical constant n is typically in a relatively narrow range of 0.45 – 0.55.

Since the HLR is defined by equation 3.1.1, the relationship for the retention time can be written in the form:

$$T = K.D/ (HLR)^{n} \quad \text{3.2.2}$$

The form of the equation demonstrates the inverse relationship between retention time (T) and hydraulic loading rate (HLR).

The median retention time in stone trickling filters is relatively short, in the order of 10 to 20 minutes. The retention time has a probability distribution due to the variable flow paths through the filter. Retention time is sensitive to hydraulic loading rates, as reflected in **Figure 3.2 (a)**. The figure shows the recorded median retention time for continuously fed pilot plant trickling filters.

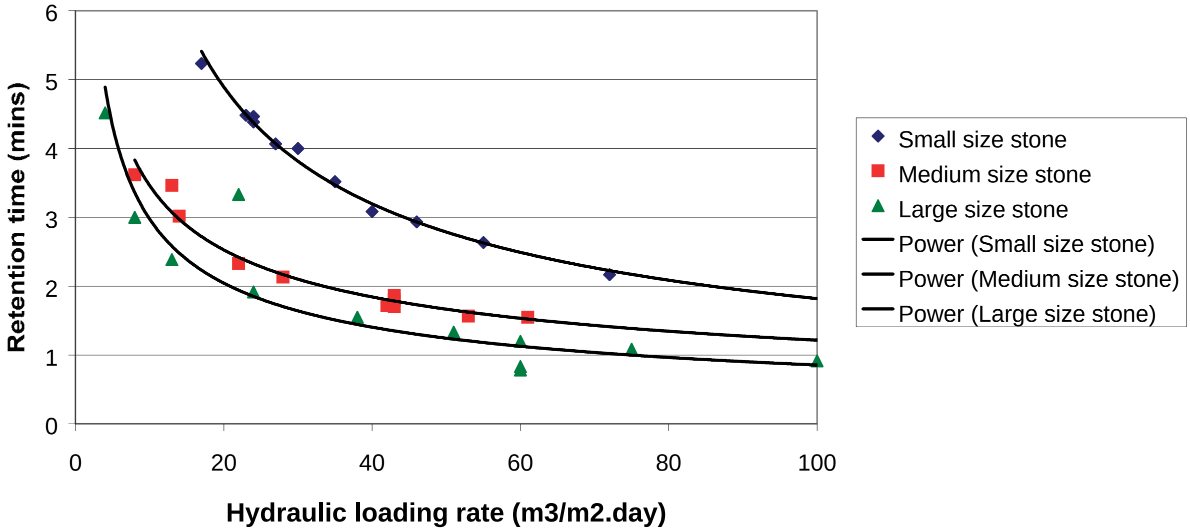


Figure 3.2 (a): Retention Time as a Function of Hydraulic Loading Rate

The figure reflects the following:

- Retention time is sensitive to hydraulic loading rate, with the retention time decreasing as the hydraulic loading rate increases.
- A sharp increase in retention time is observed at lower surface hydraulic loading rates.

The actual retention time on intermittently fed full-scale trickling filters is longer than for a continuously fed pilot plant filter. The longer retention time observed is due to the full-scale operation of successive wastewater loading and draining as the distribution arms turn.

Retention time is also influenced by the flow distribution and wastewater dosing to the filter – refer to Section 3.5 of this report.

Quantifying the wastewater retention time is a valuable tool in developing an understanding of filter performance. The hydraulic retention time observed on full-scale intermittently dosed filters is typically longer compared to pilot scale continuously dosed filters. This fact may be the primary reason for the better performance observed at full-scale installations compared to pilot scale installations.

The median retention time can also be determined by monitoring the wastewater hold-up in the filter. This is done practically by the following procedure:

- Insert a device, which can measure the flow through the filter or a defined part of the filter. This device can simply be a flat trough in which the filter effluent is collected over a specific area of the filter.
- Stop the wastewater flow to the filter.
- Collect the residual drainage from the filter, after closure of the feed flow to the filter.

The Operating Hold-up (OHU) is defined as the free water, which drains from the filter, after closure of the feed. The OHU is typically expressed as a volume per unit filter media volume. The OHU is a useful parameter since it can be related to the retention time:

$$OHU\ (V/A) = T \times (Q/A) \qquad 3.2.3$$

Where

Where	OHU	=	Operating hold-up (m^3/m^3 of filter volume)
	Q	=	Filter feed flow (m^3/min)
	T	=	Median retention time (mins)
	V	=	Filter volume (m^3)
	A	=	Filter cross sectional area

Figure 3.2 (b) shows the measured Operating Hold-up as a function of the hydraulic loading rate (HLR) for two different filter media types:

- Natural rock media with a specific surface area 65 m^2/m^3 of media.
- Cross flow plastic media with a specific surface area 112 m^2/m^3 of media.

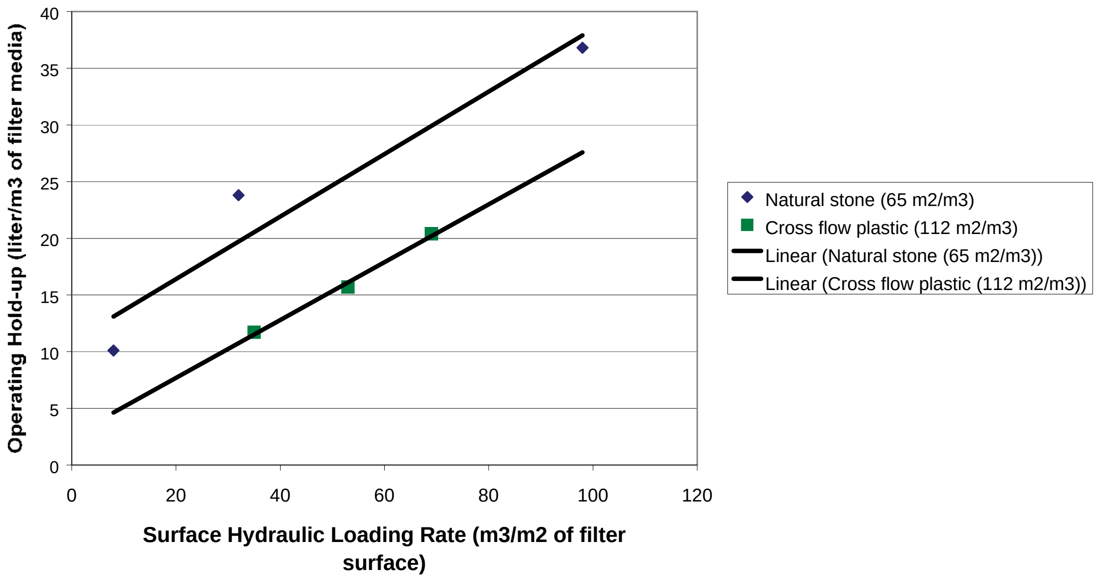


Figure 3.2 (b): Wastewater Hold-up as a Function of Hydraulic Loading Rate

The following observations can be made:

- The wastewater hold-up increases as the hydraulic loading rate increases.
- The wastewater hold-up is relatively smaller for the cross-flow plastic media, despite the higher specific surface area (m^2/m^3 of media) of the plastic media compared to the natural stone media.

Case Study - Riverview High Filter Tracer Study. The tracer study was conducted on two new high rate trickling filters with the following overall dimensions:

- Diameter = 35 m
- Media height = 3.2 m
- Number of distribution arms = 4

The filters were operated as high rate units upstream of a BNR activated sludge process. The main operating parameters at the time of doing the tracer study were as follows:

- Hydraulic loading rate = 6.5 m/day
- Organic loading rate = 820 g COD/m^3-day
- Dosing frequency = 2.3 rev/min

The results of the tracer study are illustrated in **Figure 3.2 (c)**. The results indicate:

- A wide variation of retention times in the trickling filter.

- The first tracer peak was recorded after approximately 15 minutes, while the tail of the tracer wash-out continued for more than 60 minutes.

- A stoppage of the filter distribution arms took place between 20 and 27 minutes. This stoppage may skew the results to a longer retention time.

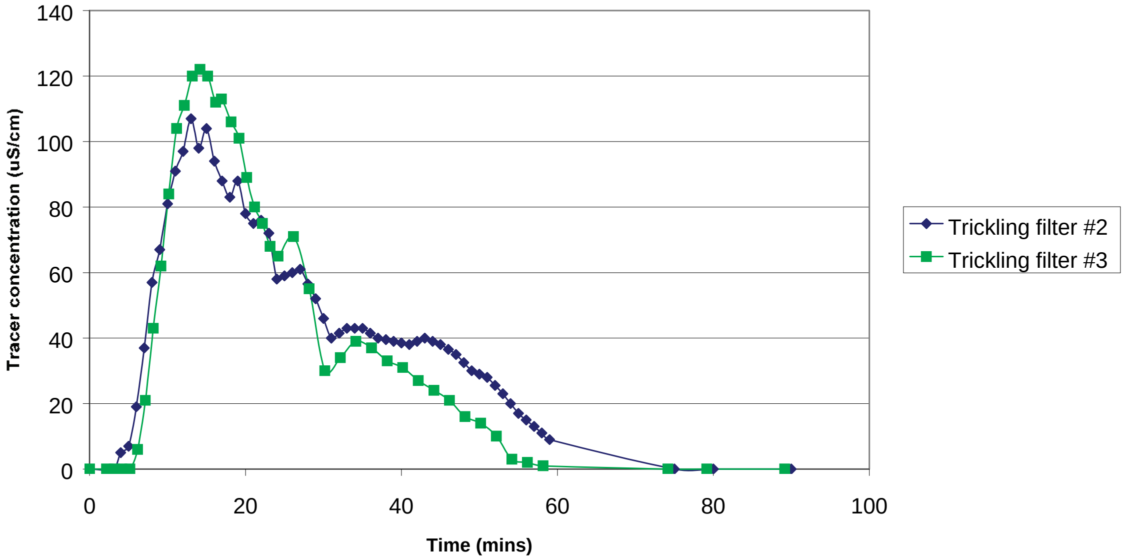


Figure 3.2 (c) : Results of Tracer Study on Riverview WWTP Trickling Filters

A tracer study provides a valuable insight into the median and variation in retention times. Quantification of retention time for different operating conditions is a valuable tool in advancing the understanding of a filter.

3.3 Flow Distribution

Trickling filters are typically equipped with rotating distribution arms. The distributor mechanism usually has 2 arms and can be hydraulically propelled or mechanically driven.

The spacing of holes in the distributor arms is critical to achieve good flow distribution. The spacing of holes decreases in a radial direction due to the larger stone media volume to be wetted. The total flow is then

$$Q+Q_r = N\Sigma Q_h \quad \text{..........} \quad 3.3.1$$

where Q = wastewater feed flow rate (m^3/day)
Q_r = recirculation flow rate (m^3/day)
N = number of holes
Q_h = flow per hole (m^3/day).

The required flow distribution is illustrated in **Figure 3.3(a)**.

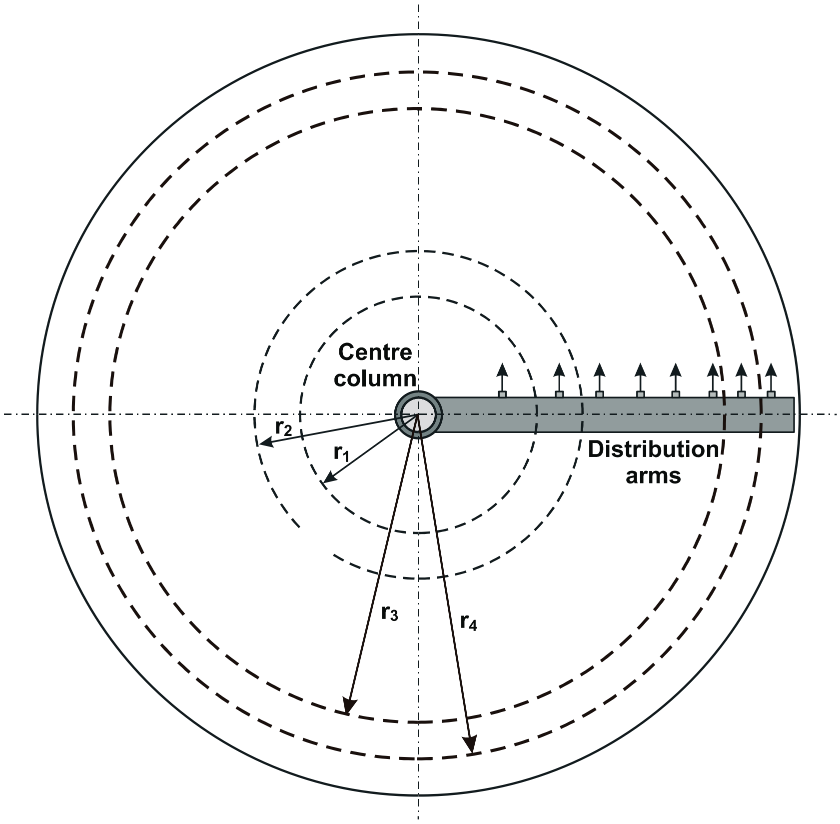


Figure 3.3 (a) : Flow Distribution to Trickling Filter

For equal flow distribution per unit filter media, the flow per distributor hole should be the same, but the spacing of the distributor holes should decrease in a radial direction.

Thus $\prod(r_2^2 - r_1^2) = \prod(r_4^2 - r_3^2) = K$ 3.3.2

Or $\left[\frac{(r_3 + r_4)}{2}\right](r_4 - r_3) = K/2\prod$ 3.3.3

The spacing between holes ($r_{i+1} - r_i$) then decreases in proportion to the distance from the centre column ($r_{i+1} + r_i$)/2.

Mechanically driven distributors can control the rotational speed and the associated dosing application. These distributors can be driven from a motor/gearbox assembly on the peripheral wall or from a motor/gearbox assembly mounted on the inside centre column. The hydraulically propelled distributors rotate to give a dosing application of once in 50 to 60 seconds.

It is advisable to test the flow distribution for different hydraulic loading rates. This can practically be done by one of two methods:

- Trough on a radial wire/rope – refer to **Figure 3.3(b**) for more detail

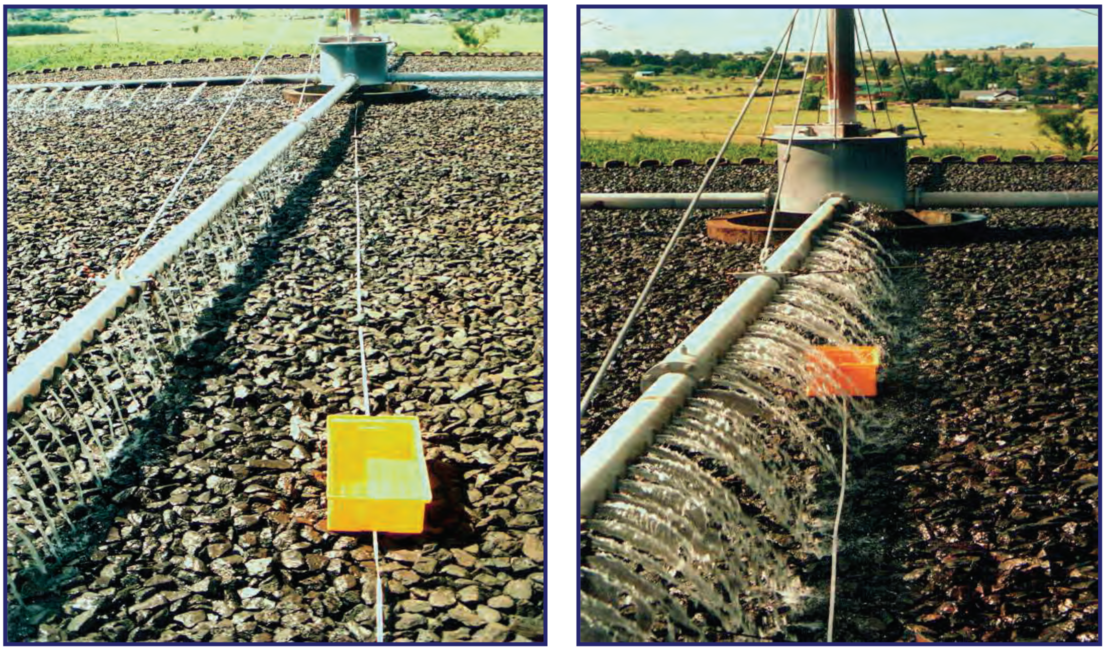


Figure 3.3 (b): Trough on Radial Wire to Measure the Flow Distribution

- Radial trough packed in a radial direction – refer to **Figure 3.3(c)** for more detail

Figure 3.3 (c): Radial Troughs Across the Filter Media

Case Study – Oberholzer Wastewater Treatment Plant. The importance of proper flow distribution across a trickling filter was demonstrated on a trickling filter at the Oberholzer Wastewater Treatment Plant, in Carletonville. The filter is designed and operated for BOD/COD and NH_3-N removal.

The demonstration involved operation of the trickling filter distribution arms at two different rotational speeds. The two operating conditions are reflected below:

Table 3.3 (a) : Trickling Filter Distribution Arms At Two Different Rotational Speeds

Operating parameter	Trickling Filter #5	
	Slow speed	High speed
1. Hydraulic loading rate (m^3/m^2-day)	4.7	5.1
2. Rotational speed (rpm)	0.4	2.0
3. Spulkraft (mm/pass)	2.0	0.45
4. Organic loading rate (g COD/m^3-day)	675	760
5. Nitrogen loading rate (g N/m^2-day)	1.2	1.6

The flow distribution of wastewater onto the trickling filter was sensitive to the rotational speed. At the higher rotational speed, the wastewater preferentially discharged on the outer perimeter of the filter. The observed flow distribution is shown in **Figure 3.3 (d)**.

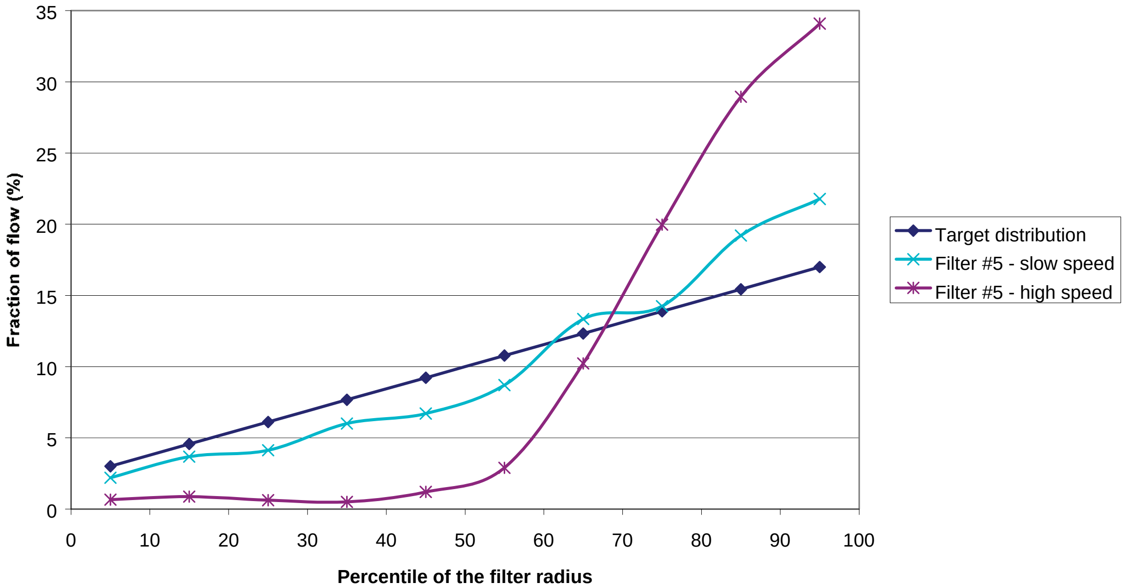


Figure 3.3 (d): Oberholzer WWTP – Flow Distribution Investigation

This shows that the flow distribution was fairly even at the slower rotational speed. Poor flow distribution was recorded for operation at the higher rotational speed.

The flow distribution across the filters influenced the effective retention time. Tracer studies were conducted on the filter operated in the two different modes and the results are reflected in **Figure 3.3 (e)**.

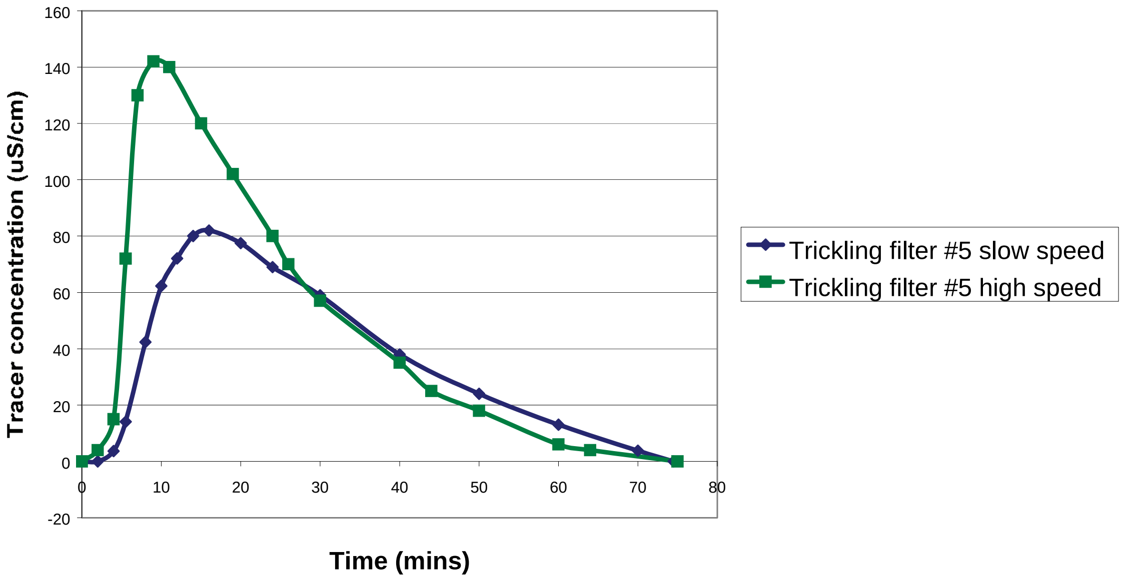


Figure 3.3 (e) : Tracer Study Results on Slow/Fast Trickling Filters

The study shows an early breakthrough of tracer from the filter operated at high rotational speed and poor flow distribution. The filter operated at slower speed with better flow distribution had a longer effective retention time.

The different hydrodynamic condition in the filter is reflected in different performance as shown below:

Table 3.3 (b): Hydrodynamic Condition in Different Speed Performance

Performance criteria	Trickling Filter #5	
	Slow speed	High speed
COD removal (%)	84%	72%
NH_3-N removal (%)	78%	51%

Poor flow distribution can, therefore, have a pronounced impact on the performance of a trickling filter.

Poor hydraulic design of trickling filters can contribute to a number of problems including:

- Spilling over the centre well during peak flow conditions – refer to **Figure 3.3 (f)** for more detail.
- Insufficient spreading due to inadequate splash plate design – refer to **Figure 3.3 (g)** for more detail.
- Discharge from distributor end-cap due to excessive pressures – refer to **Figure 3.3 (h)** for more detail.

Figure 3.3 (f): Spilling Across the Centre Distribution Well

Figure 3.3 (g): Poor Splash Plate Design and Inadequate Feed Spreading

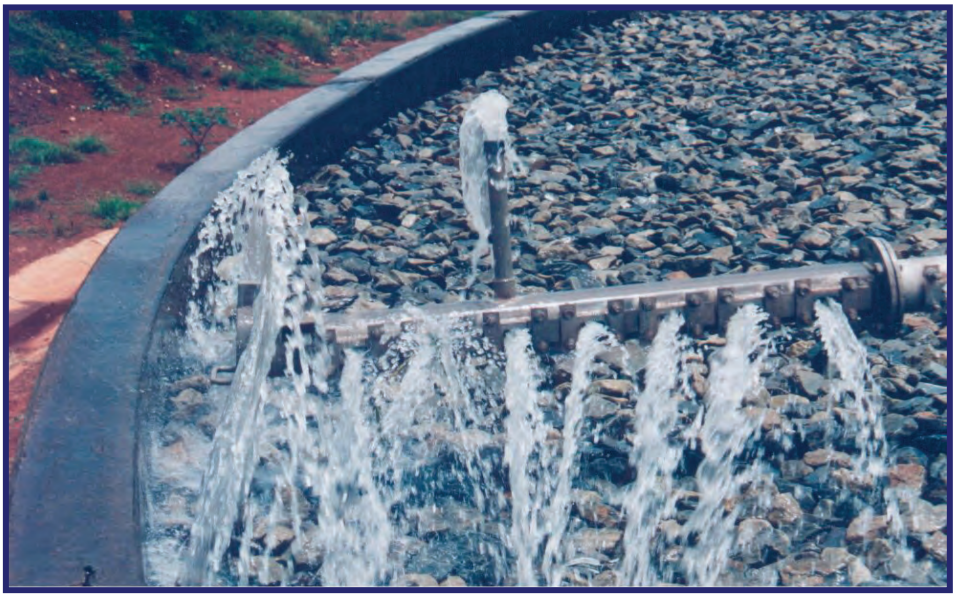


Figure 3.3 (h): Loss of Water from Distributor End Cap

Good flow distribution is essential to optimal filter performance – refer to **Figure 3.3 (i)** for an example of good flow distribution.

Figure 3.3 (i): Good Filter Feed Distribution Pays Dividends

3.4 Hydraulic Design of Flow Distributors

The flow distribution system must be designed to apply the feed wastewater evenly across the trickling fitter bed.

The basic approach to the hydraulic design of a rotating flow distribution system is presented by Droste, (1997). The approach is summarized on the basis of the **Figure 3.4** definition diagram.

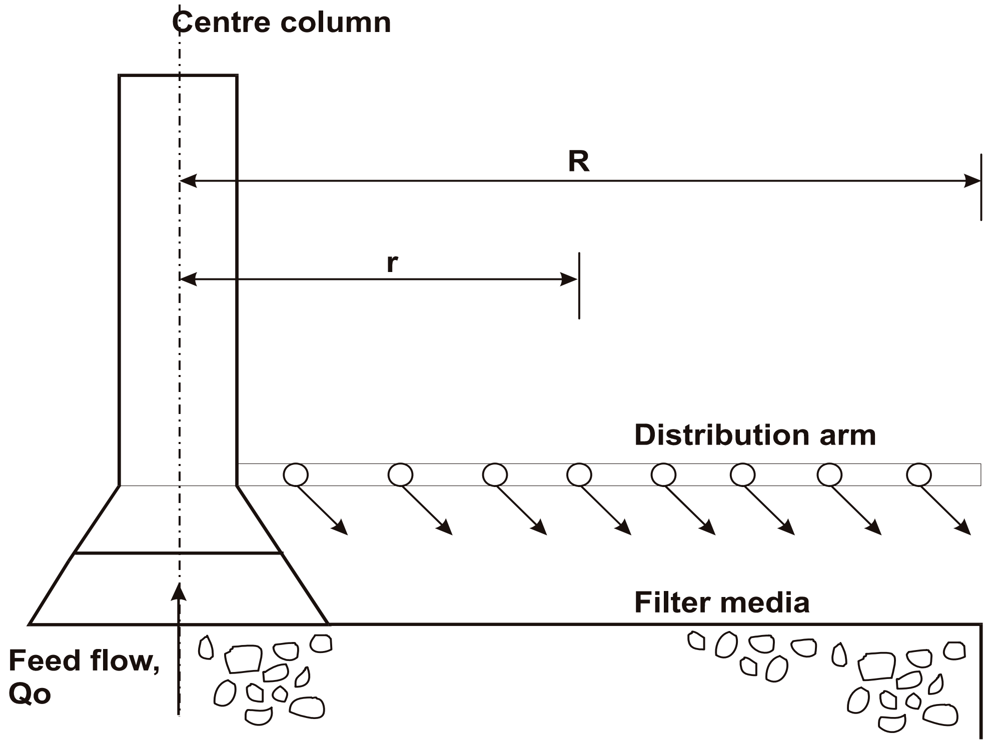


Figure 3.4 : Filter distribution definition diagram

The even flow distribution across the trickling fitter requires that

$$Q/r^2 = Q_o/R^2 \quad \text{3.4.1}$$

where Q = flow discharged over filter area bounded by radius r

Q_o = total flow discharged via distributor arm

r = radial position on filter surface

R = trickling filter radius

The wastewater flow at a radial position r is then

$$Q_r = Q_o\,(1 - r^2/R^2) \quad \text{3.4.2}$$

The hydraulic friction loss along the distributor arm can be calculated using a number of different equations. In general, the hydraulic gradient is computed as :

$$-dh/dr = f/D \cdot V^2/2g = kQ_r^2 \quad \text{3.4.3}$$

where h = total energy head
f = friction coefficient
D = distribution pipe diameter
V = flow velocity
g = gravitational acceleration

The head loss along the distributor pipe can then be calculated by substituting equation 3.4.2 into equation 3.4.3, as follows:

$$h_R = -\int_{ho}^{hf} dh = kQ_0^2 \left[\int_o^R dr - 2/R^2 \int_o^R r^2 dr + 1/R^4 \int_o^R r^4 \cdot dr \right.$$
$$= 0.59\ kRQ_0^2 \quad \text{3.4.4}$$

where h_r = total head loss over pipe length R
h_o = initial total energy head (at centre column)
h_f = final total energy head (at distribution pipe end)

The head loss from the centre column to a radial position r is then

$$h_r = 0.59\ k\ [RQ_0^2 – (R\text{-}r)\ Q_r^2] \quad \text{3.4.5}$$

The flow along the distribution pipe varies in a step-wise manner, as flow is discharged via successive ports along the length of the distribution arm. The discharge at a port can be calculated by an orifice equation:

$$q = C_d.a\ (2gh_{rs})^{½} \quad \text{3.4.6}$$

where q = discharge at a port
a = port area
h_{rs} = static pressure at radial position r

The static pressure calculation is based on a total energy balance incorporating the different terms to account for head loss, kinetic energy and rotational energy. The velocity in the distribution pipe at any radial position r, is equal to:

$$V_r = V_o – V_o\ r^2/R^2 \quad \text{3.4.7}$$

Where V_o = Q_o/A
V_r = Q_r/A
A = distribution pipe area

The head caused by the rotational motion of the distributor is as follows:

$$h_c = w^2r^2/2g$$
$$= (2\prod N/60)^2r^2/2g \quad \text{3.4.8}$$

where h_c = head caused by centrifugal force
w = angular velocity
N = rotational speed, rpm

The static head at any radial position is then determined as follows:

$$h_{rs} = h_o – 0.59\ [RQ_o^2\text{- }(R\text{-}r)Qr^2] + (2\prod N/60)^2r^2/2g – V_r^2/2g \quad \text{3.4.9}$$

The steps in the hydraulic design are summarized as follows:

- Select a distribution arm flow rate, Q_o
- Select a distribution arm diameter, (can be tapered) D
- Select a port size, a
- Select an estimated port spacing
- Select an initial total head, h_o
- Compute the hydraulic gradient and discharge from each port
- Compare the sum of all port discharges with the total distribution arm flow rate.

A number of iterations are required to reach a solution.

3.5 Flushing of Filters

It has been recognised that the performance of a trickling filter is not only dependent on the overall hydraulic loading rate (m^3/m^2-day), but also on the flushing or dosing rate. The flushing or dosing rate is dependent on the local application rate of wastewater. The concept of Spülkraft was introduced to quantify the flushing or dosing rate :

$$SK = \frac{(1000 mm/m)}{60 \min/h} \cdot \frac{(Q + Q_r)}{N.R} \qquad 3.5.1$$

where SK = flushing rate (mm/pass of arm)
Q = wastewater feed flow rate (m^3/ m^2 -h)
Q_r = recycle flow rate (m^3/m^2-h)
N = number of arms
R = rotational speed (rev per min)

It has been recognised for some time that higher flushing rate (slower rotational speed of distributor) can result in improved filter performance. This is ascribed to better biofilm control resulting from a thinner and more viable biomass, open unobstructed filter media with better oxygenation, improved media wetting efficiency and a longer biomass rest time between wastewater applications. The improved trickling filter performance is, however, restricted by the reduction in hydraulic retention time, associated with high flushing rates.

Case Study: Spülkraft as a function of rotational speed. The Spülkraft (SK) was calculated for a 30 m diameter trickling filter receiving 2 800 m^3/day for feed flow. The SK is shown in **Figure 3.5 (a)** as a function of distributor rotational speed and number of distributor arms.

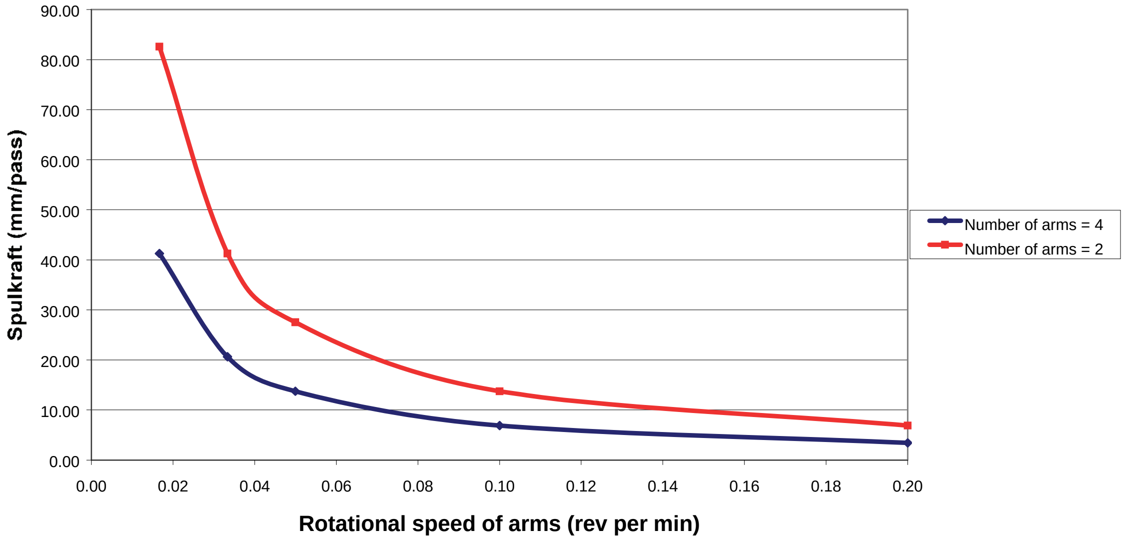


Figure 3.5 (a): Spülkraft as a Function of the Number of Distributor Arms

The SK drops rapidly below a rotational speed of 0.03 rev/min (30 mins per revolution).

Higher flushing rates can contribute to better filter performance and specifically to the following aspects :

- Elimination of periodic or seasonal biomass sloughing episodes
- Reduced odour due to the regular flushing of excess biomass from the filter
- Reduced fly breeding potential and consequently fewer fly nuisance complaints
- Ponding due to excessive biomass accumulation in the top layers of the biofilter is eliminated.

Effective flushing of a trickling filter on a daily basis is considered to be good practice.

The typical South African hydraulically propelled trickling filter is operated at a SK of 1 – 5 mm/pass. The optimum SK depends on the organic loading rate, but is typically in the range of 20 – 50 mm/pass for rock filters. Nitrifying trickling filters require a longer retention time and the following operating strategy is recommended :

- high SK flushing at night when the organic and nitrogen loading rates are low, SK > 50 mm/pass.
- low SK flushing during the day when operated at higher organic and nitrogen loading.

It is therefore critical to provide flexibility in the mechanical drive mechanism and a minimum variable speed ratio of 20:1 is recommended.

The optimum SK for different operating conditions has not been developed. Table 3.5 contains some recommendations on appropriate SK factors for cross flow synthetic media trickling filters:

Table 3.5: Recommended SK Values for Different Organic Loading Rates

Organic loading rate (g COD/m^3-day)	Operating SK (mm/pass)	Flushing SK (mm/pass)
500	10-30	$\geq$ 200
1000	15-45	$\geq$ 200
2000	30-90	$\geq$300
4000	40-120	$\geq$ 400

The optimum operating SK and flushing SK will depend on the specific filter media and on the organic loading rate. The information contained in Table 3.5 can be used as a guideline, but plant specific optimum SK-factors have to be developed.

Consideration can be given to the diurnal variation in the SK – factor to optimise both performance and effective removal of excess biosolids. Such an approach would involve operation at low SK during high flow/load conditions (typically during the day) and high SK during low flow/load conditions (typically during the night).

Effective flushing of a trickling filter is difficult to achieve, especially in random packed trickling filters. A practical test to assess the amount of excess biomass, which could be flushed from a trickling filter can be done as follows:

- Increase the flow to the trickling filter to the maximum practical.
- Divert all the flow to one of the distribution arms, again if practically possible.
- Stop the rotating distribution arm and anchor it in one position.
- Sample and analyse the TSS concentration of the filter effluent.

Any significant increase (> 300 %) of filter effluent TSS concentration would indicate a need to flush the filter. It has also been observed that purging a trickling filter of excess biosolids is more effective after a resting period. The biomass appears to enter an endogenous respiration phase when flow/load is removed from the filter. The biosolids appear to be purged more effectively from a filter after a resting period of several days.

Consideration should be given to conducting the test to establish the presence of excess biomass in the trickling filter on a regular basis, usually at least once a week initially and once a month at a later stage when a reliable data base has been developed for the plant. It is essential to have information on the filter operation (hydraulic loading, organic loading, temperature and SK) prior to the test, to allow meaningful interpretation of the test.

Relatively simple devices can be installed to manipulate the rotational speed (and SK factor). **Figure 3.5(b)** shows adjustable plates, which can brake the rotary distributor.

Figure 3.5 (b): Adjustable Braker Plates

Case Study: Control of Filter Fly Nuisance at Verulam WWTP. Durban Metro Water Service owns and operates a trickling filter module at the Verulam WWTP. A residential area is located immediately next to the plant. Local residents have been plagued by high filter fly populations supported by the trickling filter. A decision was taken to slow the filter rotating arms by installation of breaker plates at the outer ends of the arms – refer to **Figure 3.5 (c)** for more detail.

Figure 3.5 (c): Verulam Trickling Filters with Installed Breaker Plates

The breaker plates slowed the filter arms and effectively increased the SK. This resulted in more effective flushing of fly larvae eggs. The filter fly nuisance was resolved in this manner.

A new concept to describe the flushing action in a filter was developed as part of this project. The flushing force can be calculated as follows:

FF = ❑∃HLR∃D/(86400∃T)

Where FF = flushing force (N)
❑ = water density (kg/m^3)
HLR = hydraulic loading rate (m^3/m^2-day)
D = filter depth (m)
T = retention time (sec)

The correlation between the flushing force and other filter operational parameters still has to be developed.

3.6 Media Wetting Efficiency

The effective use of the available filter media surface area depends on the hydrodynamic operating conditions and the type of media. The filter media influences the maximum wettability due to the stone media shape. A perfectly spherical stone will have a high wettability, while a flaky stone will have a low wettability. This is the reason for the specification of a maximum allowable flakiness index for stone trickling filters.

The media wetting is further influenced by the flushing/dosing rate. Higher SK operation results in more effective media wetting.

The wetting efficiency is expressed as the following ratio :

$W = A_w/A_s$ 3.6.1

Where W = wetting efficiency
A_w = wetted stone media surface area (m^2/m^3)
A_s = total stone media surface area (m^2/m^3)

Crine (1990) has developed an equation to relate wetting efficiency to hydraulic loading rate:

$W = W_o (HLR)^n$ 3.6.2

Where W = wetting efficiency
W_o = reference wetting efficiency
HLR = hydraulic loading rate (m^3/m^2-day)
n = empirical constant

In general, the achievable wetting efficiency is low for densely packed random filter media. The achievable wetting efficiency is high for structured filter media.

The wetting efficiency for natural stone media is typically low ranging from 0.2 to 0.6. Guidelines have been published on the minimum hydraulic loading rate for effective media wetting. For natural stone filters an overall hydraulic loading rate of 20 m^3/m^2-day is recommended. For synthetic media filters an overall hydraulic loading rate of 45 m^3/m^2-day is usually recommended. This will have to be confirmed by the media supplier. The overall hydraulic loading rate for effective wetting may be decreased provided that flushing control (high SK) is introduced.

Chapter 4

4 VENTILATION AND OXYGEN TRANSFER

Sufficient air supply to any aerobic biological treatment process is critical to optimum performance. Trickling filters are not an exception and this aspect is often neglected during design and operation. It is not reasonable to expect good performance from a suspended growth reactor, such as activated sludge, without an adequate air supply. The same statement applies to a trickling filter installation.

4.1 Oxygen Requirements

Trickling filter oxygen requirements will depend on the wastewater composition fed to the filter. This may include some recycle streams. The total COD concentration may be split into three fractions:

- COD metabolised to build biomass
- COD oxidised to CO_2
- Non-biodegradable COD

An approximate equation of the oxygen requirement for carbonaceous material stabilisation:

$$OD_c = \left(1 - f_{up} - f_{us}\right)\left[1 - 1.48\, Y_n\right] COD \quad \text{.....................................} \; 4.1.1$$

where OD_c = carbonaceous oxygen demand (mg/ℓ)
f_{up} = fraction of un-biodegradable particulate COD, typically in settled domestic wastewater = 0.08 - 0.14
f_{us} = fraction of un-biodegradable soluble COD, typically in settled domestic wastewater = 0.04 –0.06
Y_n = biosolids yield (kg VSS/kg COD removed)
= 0.2 – 0.3 for rock filters
1,48 = ratio of VSS / COD
COD = feed wastewater Chemical Oxygen Demand (mg/ℓ)

The oxygen requirement for nitrogenous material oxidation is as follows:

$$OD_n = 4.6\,(1 - f_{un})\,TKN \quad \text{..} \; 4.1.2$$

where OD_n = nitrogenous oxygen demand (mg/ℓ)
f_{un} = un-biodegradable nitrogen fraction, typically in settled domestic wastewater = 0.01 – 0.03
TKN = settled wastewater Total Kjeldahl Nitrogen concentration (mg/ℓ)

A fraction of the oxygen demand may be satisfied by denitrification of nitrate.

Case Study – Trickling Filter Oxygen demand. A natural rock filter is packed with a nominal 45-65 mm stone. The filter overall dimensions are:

- Diameter = 21 m
- Height = 3.5 m

The filter receives an average feed consisting of two streams:

- Primary effluent @ flow of 1 200 m^3/day with COD = 500 mg/ℓ, TKN = 45 mg/ℓ
- Centrate @flow of 50 m^3/day with COD = 1 500 mg/ℓ, TKN = 620 mg/ℓ.

The carbonaceous oxygen demand:

$$OD_c = (1 - f_{up} - f_{us})\,[1 - 1.48\,Y_n]\,COD \quad \text{(refer to 4.1.1)}$$

where f_{up} = 0.07
f_{us} = 0.06
Y_n = 0.25 kg VS/kg COD

COD = (1 200 x 500 + 50 x 1 500)/1 000
= 675 kg/day

OD_c = (1 – 0.07 – 0.06) (1 – 1.48 x 0.25) 675
= 370 kg O_2/day

The nitrogenous oxygen demand, without any credit for biosynthesis or denitrification:

$$OD_n = 4.6\,(1 - f_{un})\,TKN \quad \text{(refer to 4.1.2)}$$

where f_{un} = 0.03
TKN = (1 200 x 45 + 50 x 620)/1 000
= 85 kg/day

OD_n = 4.6 (1-0.03) 85
= 379 kg/day

The total filter oxygen demand is, therefore, 1 054 kg/day. Further allowance may have to be made for peak flow and load conditions.

4.2 Natural Draft Ventilation

Natural draft ventilation relies on a difference in the air density inside the trickling filter structure and the ambient air density. The air temperature and humidity mainly determine the air density.

The air pressure differential set up in the filter is:

$$\Delta P = (Pa - Pf)gD \qquad 4.2.1$$

where
ΔP = pressure differential (Pa)
Pa = ambient air density (kg/m^3)
Pf = filter air density (kg/m^3)
g = gravitational acceleration
= 9.8 m/s^2
D = filter depth (m)

Figure 4.2 (a) shows air density as a function of temperature and humidity. The air diversity decreases as the humidity increases.

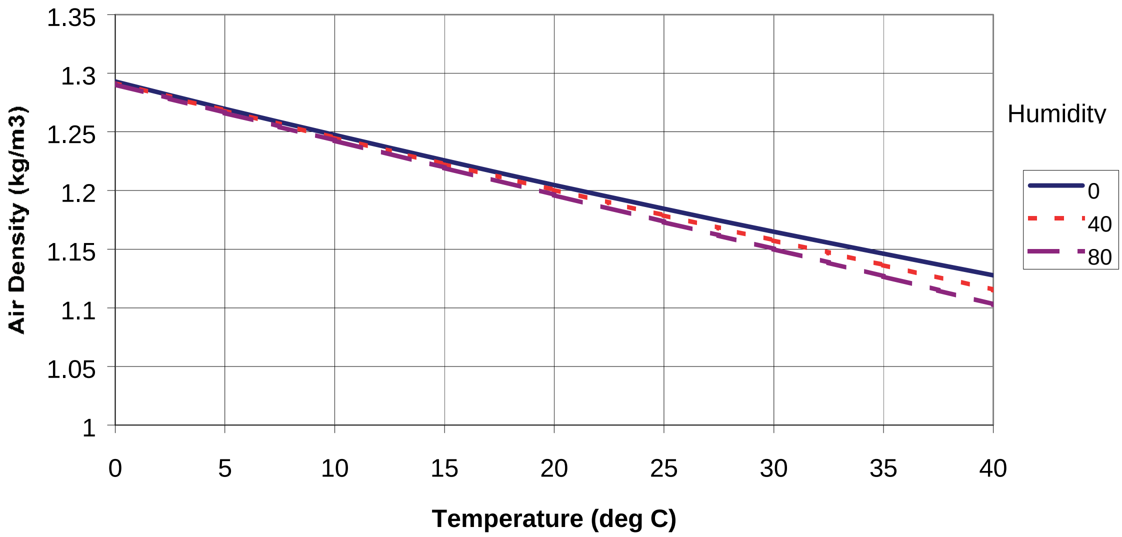


Figure 4.2 (a) : Air Density as Function of Temperature and Humidity (Atmospheric Pressure = 760 mmHg)

This air pressure differential is the driving force to natural ventilation. Two generic situations can develop:

- **Downdraft Flow** when the wastewater temperature is *lower* than the ambient air temperature. This is a typical summer condition. The natural ventilation is assisted by the humidity gradient across the filter depth – refer to **Figure 4.2 (b)**.

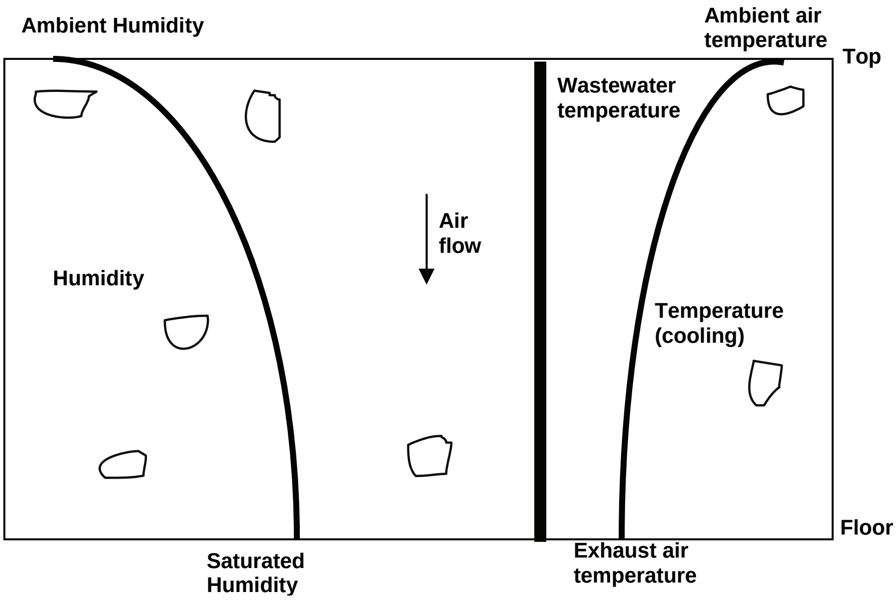


Figure 4.2(b): Natural Downdraft Ventilation

The hot ambient air is cooled by the colder wastewater trickling down the filter media. The humidity of the air is also increased as the air flows through the trickling filter. The nett effect is a more humid and colder air, resulting in a nett increased air density and downdraft flow.

- **Updraft Flow** when the wastewater temperature is *higher* than the ambient air temperature. This is a typical winter condition. The natural updraft ventilation is, further assisted by the humidity gradient across the filter depth – refer to **Figure 4.2 (c)**.

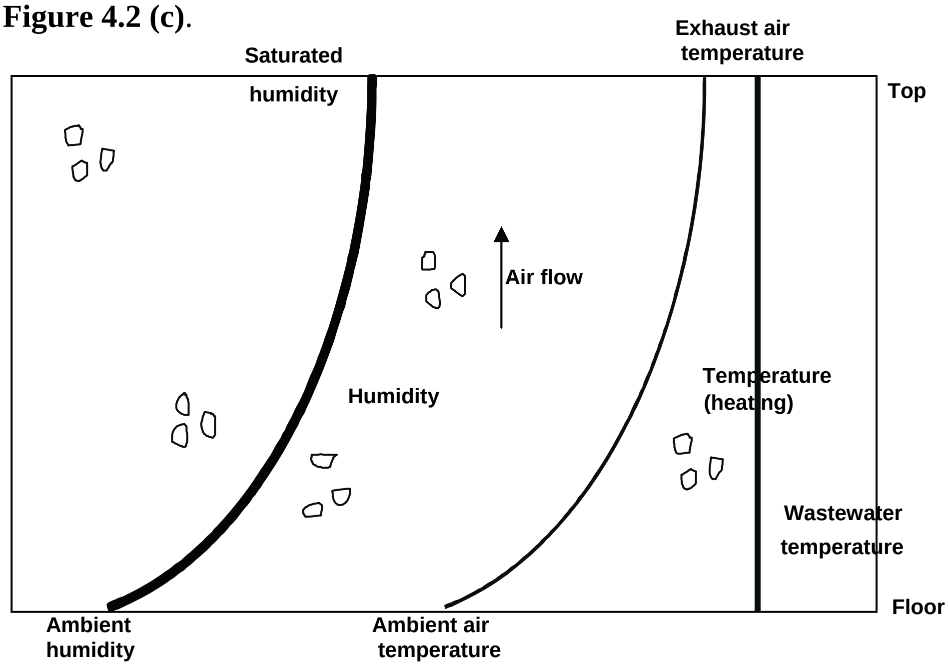


Figure 4.2 (c): Updraft Situation – Wastewater Temperature Higher than Ambient Air Temperature

The cold ambient air is heated by the hotter wastewater trickling down the filter media. As the air flows through the filter the humidity also increases, which further decreases the air density. The updraft flow will have a nett reduced density due to the combined effect of a hotter air (lower density) and a more humid air (lower density). The flow will be updraft.

There are many combinations of wastewater temperature and ambient air temperature, where the differential pressure may be insufficient to drive an adequate air flow.

Sufficient allowance must be made to allow air flow and the typical design standards that apply to natural rock filters are:

- Unobstructed peripheral air flow area equal to at least 15% of the filter gross surface area
- Under-drains, which allow for 50% of the total crossectional area (during peak flow conditions) to accommodate air flow.

4.3 Pressure Drop

Schroeder and Tchobanoglous (1976) proposed a conservative expression based on temperature and not incorporating a humidity term, to calculate the pressure differential across a filter:

$$T_m = (T_1 - T_2) / \log_e (T_1 / T_2) \quad \text{.........4.3.1}$$

$$\Delta P = C[1/T_a - 1/T_m]D \quad \text{.........4.3.2}$$

where
T_m = natural log mean air temperature (^oC)
T_1, T_2 = inlet/exhaust air temperature (^oC)
T_a = ambient temperature (°C)
C = conversion constant
D = filter depth (m)

The pressure differential set up by the natural draft effect has to provide sufficient drive to overcome the head loss through the filter media:

$$\Delta P_a = N(V^2/2g) \quad \text{.........4.3.3}$$

where
ΔP_a = air flow head loss (m)
N = filter resistance
V = superficial air velocity (m/sec)
g = gravitational acceleration
= $9.8\ m/s^2$

Research conducted by Dow Chemical Company indicated that the rock filter resistance is:

$$N = 1.9\ D \exp (0.77 \times 10^{-5} * L/A) \quad \text{.........4.3.4}$$

where D = filter depth (m)
L = hydraulic loading (m^3/day)
A = filter cross-sectional area (m^2)

Even at a low temperature differential (5^oC) between the wastewater and air, natural draft effects provide sufficient oxygenation for filters operated at low organic loading rates (<1 000 g COD/m^3-day). It is, however, inevitable that for some period of the day and for some time of the year, the temperature differential may be insufficient to drive natural draft ventilation.

4.4 Forced Draft Ventilation

In trickling filters receiving a high organic loading rate (> 1 000 g COD/m^3-day), it is advisable to consider forced draft ventilation. The installation of a forced draft blower is determined by two aspects:

- Pressure drop across the filter, which is small and typically less than 10 - 20 mm water pressure.
- Airflow required to satisfy the filter oxygen needs. The air flow requirement can be calculated as:

$$AFR = (OD_c + OD_n) / [P_a \text{ x } M_o \text{ x } ❈]/24 \quad \text{.......... 4.4.1}$$

where AFR = air flow requirement (m^3/min)
OD_c = carbonaceous oxygen demand (kg O_2/day)
OD_n = nitrogenous oxygen demand (kg O_2/day)
P_a = air density (kg/m^3)
M_o = oxygen content of air
= 0.23 kg/kg
η = oxygen transfer efficiency

The oxygen transfer efficiency is a critical assumption in the air flow requirement calculation. The typical design assumptions are:

η = 4-5 % for higher loaded filters, > 1 000 g COD/m^3-day.

η = 2-3 % for lower loaded filters < 500 g COD/m^3-day.

The energy requirement for forced draft blowers is low. At the small pressure drop across a trickling filter, an axial flow blower can deliver approximately 200 - 250 Nm^3/min of air per kW installed power.

The forced draft ventilation should be installed with the following considerations in mind:

- Forced ventilation should assist the dominant natural draft ventilation pattern

- Airflow distribution is important and adequate allowance must be made in the filter under-drain system for ventilation.

- Odour contained in the forced draft ventilation may have to be removed. This will then require a down draft arrangement with foul air scrubbing.

Case Study – Trickling Filter Air Flow Requirements. Consider the case study developed in Section 4.1 of the report. The total oxygen demand was estimated to be 1 054 kg/day.

The air flow requirements are:

$$AFR = (OD_c + OD_n)/(P_a \times M_o \times ✳)/24/60$$

Where P_a = 1.23 kg/m^3 at standardised conditions (20°C, 1 atm)
M_o = 0.23 kg O_2/kg air
✳ = 2.5 % (low organic load)

$$AFR = 1\,054/(1.23 \times 0.23 \times 0.025)/24/60$$
$$= 104 \text{ m}^3/\text{min}$$

The estimated air fan power requirement is therefore, 104/225 kW = 0.5 kW.

Chapter 5

5 TRICKLING FILTER MEDIA

The selection of the trickling filter media is probably the single most important design decision in the construction of a filter.

5.1 Type of Stone Media

Natural stone media has to be mined from a local source due to the cost of haulage over long distances. A large variety of suitable geological materials are available in Southern Africa. These materials are mined for aggregate and filler in the construction industry. More than one natural stone source will usually be available and the preferred types of rock include:

- Basaltic rock (andesites, basaltic, etc)
- Gabbro rock (diorite, norites)
- Granite rock (granites)
- Quartzite rock (quartzites)

Sedimentary rocks such as dolomites may also be considered. The long term durability of the sedimentary rock must be confirmed.

5.2 Characterisation of Stone Media

The media properties are of interest due to the significant impact on trickling filter performance. The key properties of interest include:

- Size of rock, as reflected by size distribution
- Void space between rock
- Shape of rock, as reflected by flakiness
- Surface area per unit volume (m^2/m^3 of media)
- Durability

These physical properties determine a number of trickling filter process parameters such as ability to support biological growth, effective flushing to maintain a healthy biofilm, even distribution of wastewater, free ventilation to ensure aerobic conditions, biomass accumulation and sloughing.

The size distribution of rock media as specified by BS1438:1971 is reflected below in **Table 5.2 (a)**

Table 5.2 (a) : Size Distribution of Trickling Filter Stone (% Passing)

BS410 Test Sieves (mm)	**Nominal Size (mm)**			
	63	**50**	**40**	**28**
	%	**By Mass**	**Passing**	
75	100	-	-	-
63	85-100	100	-	-
50	0-35	85-100	100	-
37	0-5	0-30	85-100	100
28		0-5	0-40	85-100
20			0-5	0-40
14				0-7

An even larger stone size, nominal size 75 mm may also be considered for high rate applications. In general the preferred stone size for different trickling filter applications is as follows:

- Tertiary nitrification filters – 28 to 40 mm
- Combined BOD/COD removal and nitrification filters – 40 to 63 mm
- High rate BOD/COD removal filters – 63-75 mm

In general, the smaller stone size would provide a higher specific surface area which has the following benefits:

- Longer residence time due to increased wastewater hold-up
- More surface area to enhance the attached biogrowth

However, smaller stone size and higher specific area do not necessarily translate into enhanced trickling filter performance. Smaller stone media are more prone to accumulation of excess biomass, poor ventilation, preferential flow paths and ponding. Unless these aspects are addressed, little benefit from using smaller stone media will be realised.

The specific surface area (m^2/m^3 of media) of a filter media gives an indication of the potential to support biological growth. The specific surface area and related physical properties for stone media are summarised below:

Table 5.2(b) : Physical Properties of Natural Stone Media

Stone size, nominal (mm)	Specific surface area (m^2/m^3)	Bulk density (kg/m^3)	Void space (%)
28	75	1 600	45
40	60	1 550	50
50	53	1 450	55
63	45	1 400	60

The British Standard Specification BS1438:1971 for "*Media for Biological Percolating Filters*" is generally applied to the selection and quality control of natural stone media.

Two standards documents are practically used in the specification of natural stone media:

- BS1438:1971 - Media for Biological Percolating Filters

- BS812:Part 1:1975 – Sampling and Testing of Mineral Aggregates, Sands and Fillers.

Care must be taken when consulting different international references and documentation quoting stone media sizes. The method for determining effective stone size may differ between different countries.

5.3 Media Depth

Historically most natural rock filters were constructed to a depth of 1.5 to 2.5 m, mainly due to structural constraints. More recently, using modern interlocking block construction, trickling filter structures approach 3 to 4 m depth.

There is still a controversy over the benefits of deeper trickling filters. Some of the filter design equations would imply that it is beneficial to go for the deeper filter depths. The minimum wetting requirements are more achievable with deeper filters, so the media should be more effectively flushed. Other process parameters also play a role, such as the recirculation rate, which may confound attempts to demonstrate the benefits of deeper trickling filters under all circumstances. Deeper filters will have the following benefits:

- Improved natural draft ventilation due to the increasing driving force for air pumping through the filter.

- Better flow distribution over a smaller cross-sectional area, which should improve media wetting.

- Smaller footprints of the structure, which could economise on the plant land requirements.

5.4 Synthetic Filter Media

Synthetic (plastic) filter media have gained general acceptance due to the higher specific surface area (m^2/m^3) and increased voidage, compared to stone media. These features have allowed higher hydraulic and organic loads, while maintaining adequate ventilation and oxygenation. Effective media wetting is a prerequisite to achieve the desired performance under high flow and load conditions.

Synthetic media can be broadly classified into the following categories:

- Random packed media
- Vertical flow media (VF)
- Cross flow media (XF)

The typical physical properties of South African synthetic filter media (Terbo-Pac, 2002) are summarised below:

Table 5.4 : Typical Synthetic Filter Media Properties

Media type	Specific surface area (m^2/m^3)	Bulk density (kg/m^3)	Void space (%)
Random Pack			
Various	80-160	30-80	>95
Vertical flow			
Terbo-Flo (previously Flocor)	100	24	
Cross flow			
Terbo-Pac TBX1200	233	34	>95
Terbo-Pac TBX1900	148	26	>95
Terbo-Pac TBX2700	112	20	>95

The low density (80-120 m^2/m^3) synthetic media is used for higher rate (carbon removal) installations. Tertiary nitrification filters typically employ the intermediate density (140-230 m^2/m^3) media.

Chapter 6

6 CARBON REMOVAL

Trickling filters are very effective in the removal of carbonaceous compounds as measured by BOD/COD. The carbon removal performance of a trickling filter is mainly determined by:

- Organic loading rate
- Hydrodynamic aspects of operation, specifically even flow distribution.
- Air supply and adequate ventilation
- Filter media, especially sufficient wetting of the media.
- Biological growth in active thin biofilm with removal of excess, decaying biomass.
- Temperature of wastewater

6.1 Carbon Loading Rate

The volumetric organic loading rate (VOLR) is defined as follows:

$$VOLR = (Q * COD_i)/V \qquad 6.1.1$$

where VOLR = volumetric organic loading rate (g COD/m^3-d)
Q = feed flow rate (m^3/day)
COD_i = feed wastewater COD concentration (mg/ℓ)
V = filter media volume (m^3)

The organic removal rate is defined as follows:

$$VORR = Q(COD_i - COD_e)/V \qquad 6.1.2$$

Where VORR = volumetric organic removal rate (g COD/m^3-d)
COD_e = filter effluent COD concentration (mg/ℓ)

Trickling filters are broadly classified in terms of the VOLR into the following categories:

- High rate roughening filters operated to achieve 40-60 % COD removal at loading rates of 2 000-6 000 g COD/m^3-day.

- Carbon removal filters operated to achieve BOD and TSS concentrations in the plant effluent of < 30 mg/ℓ, at loading rates of 750 - 2 000 g COD/m^3-day.

- Combined carbon/nitrogen removal filters operated to achieve both BOD/COD and partial nitrogen oxidation at loading rates of 250 - 750 g COD/m^3-day.

- Nitrification filters operated to achieve a high degree of nitrification at organic loading rates of < 250 g COD/m^3-day.

6.2 Modelling of Carbon Removal

The prediction of trickling filter carbon removal is complicated by the fact that, unlike suspended culture treatment systems, the flow pattern and biology are non-uniform. The filter flow pattern cannot be defined by a relatively simple plug-flow or completely mixed model, but has to be described by a non-ideal model. The biological life in a trickling filter also varies spatially. A different microbial population will be present in the top layers of the filter, which are exposed to the higher influent wastewater BOD/COD concentrations, compared to the bottom layers of the filter.

Numerous models have been proposed to describe BOD/COD removal. These models can be classified into three groups:

- Empirical loading-based models

- Empirical hydraulic-based models

- Mass transfer based models

Research on a number of South African carbon removal trickling filters has indicated that the BOD/COD removal may be modelled by the modified Velz equation:

$$S_e / S_o = \exp\left[-K.A_w.D/(Q/A)^n\right] \quad \text{6.2.1}$$

which is also expressed as:

$$S_e / S_o = \exp\left[-K_a.D/(Q/A)^n\right] \quad \text{6.2.2}$$

where S_o = feed BOD/COD concentration (mg/ℓ)
S_e = effluent BOD/COD concentration (mg/ℓ)
A_w = wetted media surface
K, K_a = empirical constants
D = trickling filter depth (m)
Q/A = surface hydraulic loading rate (m^3/m^2-day)

Many researchers have, however, confirmed that the empirical constant, K_a is not universal and changes due to the influence of:

- Filter height
- Organic loading rate
- Filter media properties
- Wetting efficiency of filter media

It was found useful to normalise the empirical constant, K_a, between different filter applications in the following manner:

$$K_x = K_a (D_a/D_x)^{0.5}(S_a/S_x)^{0.5}$$

Where
K_a = reference empirical constant
K_x = site specific empirical constant
D_a = reference trickling filter height
D_x = site specific trickling filter height
S_a = reference feed BOD/COD concentration
S_x = site specific BOD/COD concentration

Many natural stone filters have recirculation and the empirical constant should also take this into account. A generally agreed protocol for adjusting the K_a value to account for different recirculation rates has not been developed.

WEF (2000) proposes the following empirical constant, K_o, for a reference trickling filter, 2 m high and receiving a feed BOD = 140 mg/ℓ (COD assumed to be 280 mg/ℓ.

Table 6.2 : Empirical Rate Constant Values

	R = 1	**R = 2**
K_a $(m^3/day)^{0.5}/m^2$	2.4	2.5

The appropriate empirical constant to apply to trickling filter treatment of domestic wastewater is shown graphically in **Figure 6.2(a)**.

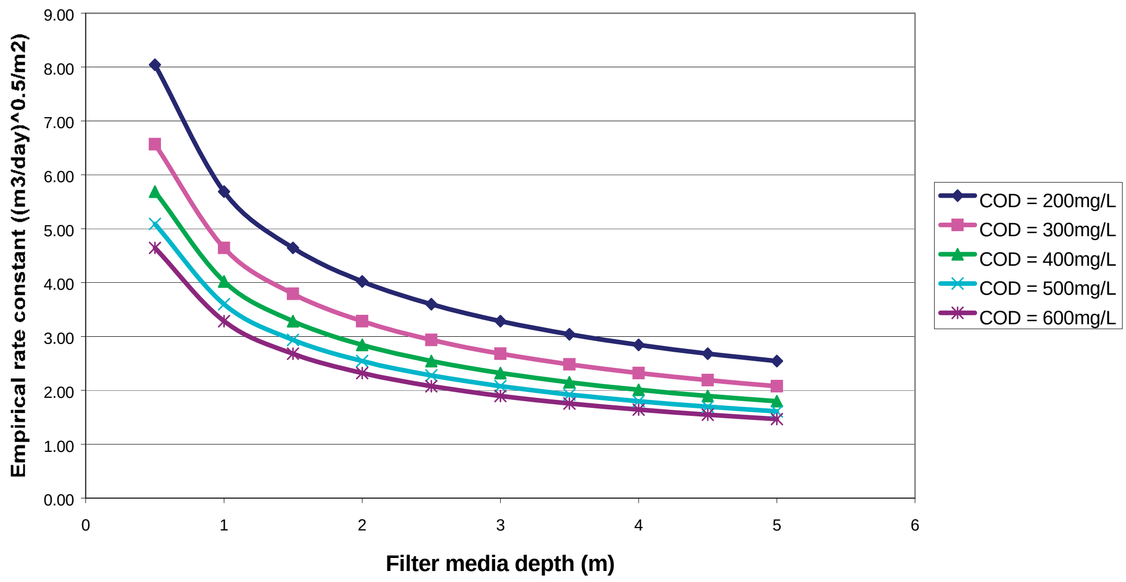


Figure 6.2 (a): Empirical Rate Constant as Function of Filter Depth and Feed COD Concentration

Influence of Recirculation

If a fraction of the trickling filter effluent is recycled, this expression has to be modified. The effective feed concentration then becomes:

$$S_o^1 = [QS_o + RQS_e]/[(1 + R)Q] \quad \text{.......... 6.2.3}$$

$$= [S_o + RS_e]/[1 + R]$$

where R = recycle ratio
S_o^1 = blended feed BOD/COD concentration (mg/ℓ)

The surface hydraulic loading rate is also modified by recirculation as follows:

$$(Q/A)^1 = (1 + R)\, Q/A$$

Substituting these modified expressions into the original model equation gives:

$$S_e\,(1 + R)/(S_o + RS_e) = \exp\,[-K_a.D/[(1 + R)\,Q/A]^n]$$

$$(1 + R)\,S_e = (S_o + RS_e)\exp\,[-K_a.D/[(1 + R)\,Q/A]^n]$$

$$(1 + R)\,S_e - R.S_e \exp\,[-K_a.D/[(1 + R)\,Q/A]^n] = S_o \exp\,[-K_a.D/[(1 + R)\,Q/A]^n]$$

$$(S_e/S_o)^{-1} = [(1 + R)\exp\,(K_aD/[(1 + R)\,Q/A]^n] - R$$

This latter expression is commonly used to model the trickling filter carbon removal performance with recirculation. Some researchers have suggested that when recirculation is practised and the influent wastewater BOD/COD is diluted, that the empirical constant should also be modified as :

$$K_a^1 = K_a (S_o/S_o^1)^{0.5}$$

$$= K_a \left[\frac{S_o(1+R)}{S_o + RS_e}\right]^{0.5}$$

Case Study – Application of the Empirical Filter Equation. The rock trickling filter has the following dimensions:

- Depth = 2.75 m
- Diameter = 23 m

The filter receives a feed primary effluent flow of 1 000 m^3/day containing a total COD concentration of 380 mg/ℓ. The filter is operated with a recycle rate of 1 000 m^3/day (R=1). The filter loading and predicted performance is summarized as follows:

- Wastewater characterisation:

  Total COD concentration = 380 mg/ℓ

  Biodegradable fraction = 0.82

  Biodegradable COD concentration = 323 mg/ℓ

- Hydraulic and organic loading:

  OLR = (Q.S)/V

  = (1 000 x 380)/1142

  = 333 g COD/m^3-day

  HLR = Q/A

  = (1 000)/415

  = 2.4 m^3/m^2-day

- Empirical rate constant:

  $K_x = K_a(D_a/D_x)^{0.5}(S_a/S_x)^{0.5}$

  $= 2.4\ (2/2.75)^{0.5}(280/323)^{0.5}$

  $= 1.9\ (m^3/day)^{0.5}/m^2$

- Filter effluent degradable COD:

  $S_e = S_o\left[(1+R)\exp\left(K_a\ D[(1+R)(Q/A)]^n\right) - R\right]^{-1}$

  $= 323\left[2\exp\left[(1.9x2.75)/(2x2.4)^{0.5}\right] - 1\right]^{-1}$

  = 15 mg/ℓ

- Filter effluent total COD:

  Se = 15+ (380-323)

  = 72 mg/ℓ

Case Study – Gammams WWTP COD Removal. Gammams Wastewater Treatment plant receives a predominantly domestic wastewater. A fraction of the wastewater is treated in natural stone trickling filters. The filters were operated in two (2) modes to develop an understanding of the COD removal performance:

- Low-intermediate COD loading in the range of 100 – 800 g COD/m^3-day.
- High COD loading in the range of 1 000 to 7 000 g COD/ m^3-day.

The performance of the low-intermediate COD loaded filter is illustrated in **Figure 6.2 (b)**.

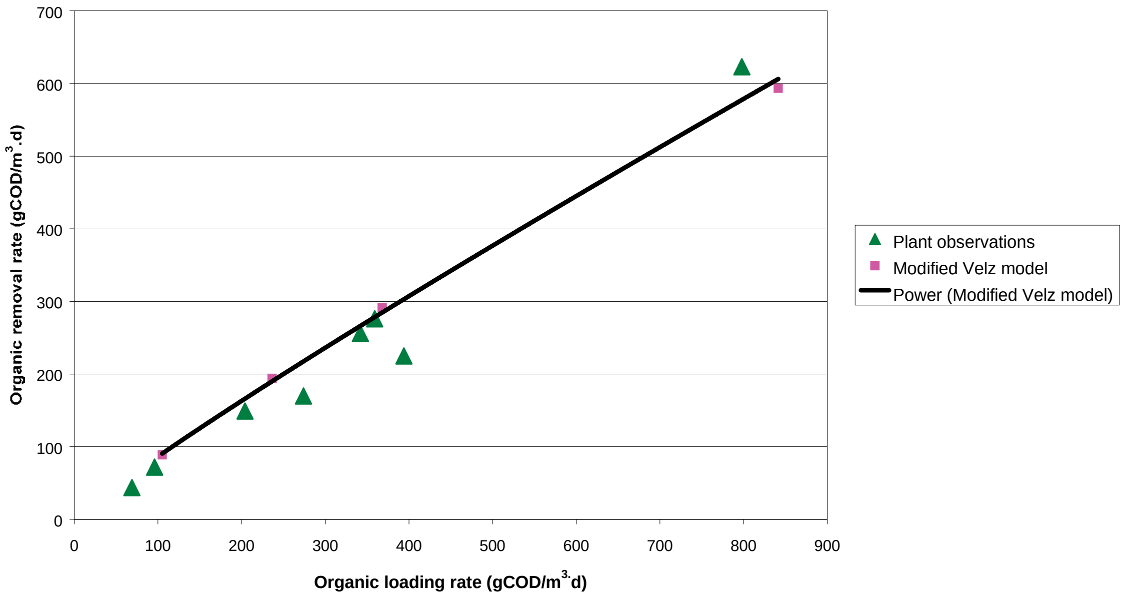


Figure 6.2 (b) : Organic Removal Performance of a Low Rate Trickling Filter

The figure shows that the filter organic removal increased as the loading rate increased. The average percentage COD removal was 72 %. The modified Velz-model could be fitted reasonably well to fit the full-scale observation. The model was calibrated using an empirical constant Ka = 2 $(m^3/day)^{0.5}/m^2$.

The performance of the high COD loaded filter is shown in **Figure 6.2 (c)**

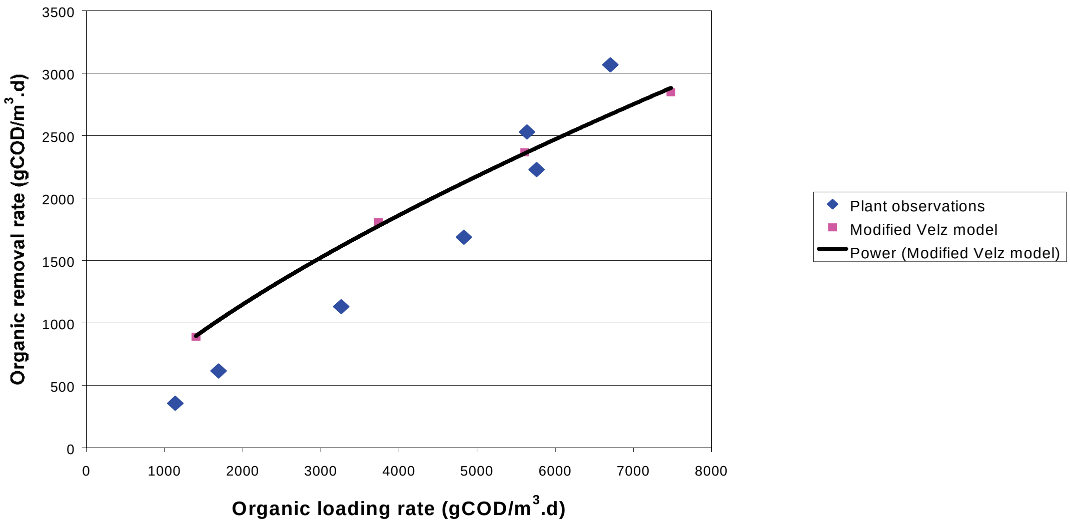


Figure 6.2 (c) : Organic Removal Performance of a High Rate Trickling Filter

The figure again shows that the capacity of the filter to remove organics increases as the organics loading increases. The average percentage COD removal was 40 %. The modified Velz equation could be fitted to the plant observations, but the fit was not as good as the low-intermediate rate filters. Different COD removal mechanisms may change in relative importance over the wide range of COD loading evaluated. It may be an indication that an empirical approach, such as the Velz model may have to be calibrated for relatively narrow COD loading ranges.

Case Study – Impact of Recirculation on Trickling Filter Performance. The Baviaanspoort Pilot stone trickling filters were operated at different recycle rates. It was observed that the filter performance improved substantially at high recycle rates. **Figure 6.2(d)** illustrate the observed trickling filter COD removal with and without recirculation.

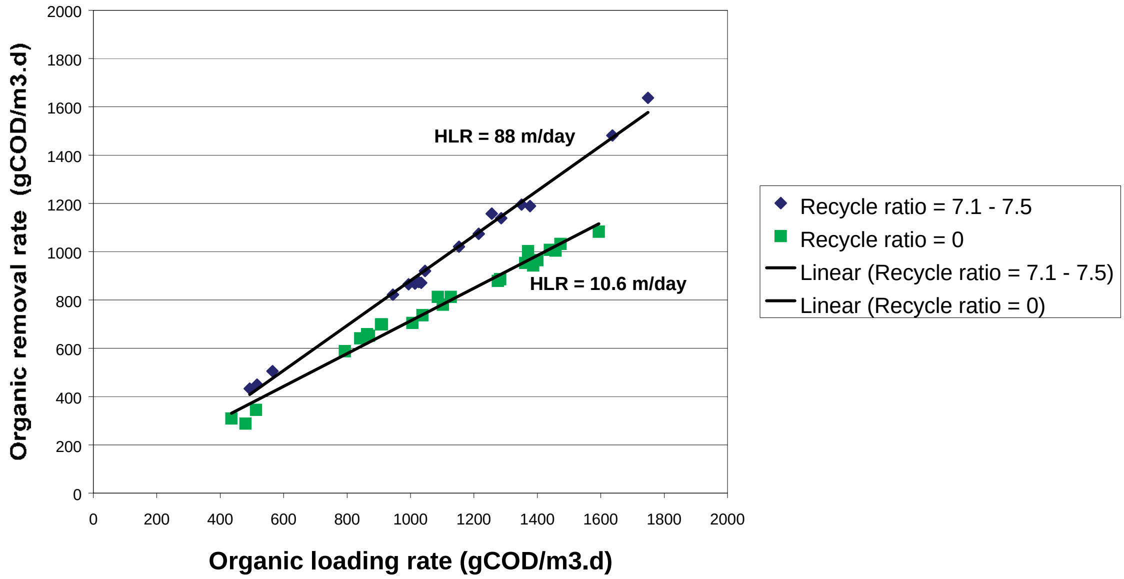


Figure 6.2(d) : Impact of Recirculation on COD removal

The filter performance improved from an average of 71 % COD removal (no recirculation) to an average 88 % COD removal (with high recirculation, R = 7 - 7.5) The improved performance of the high recirculation filter could be ascribed to better aeration efficiency due to the turbulent flow through the filter, improved wetting of the filter media and multiple contact between the wastewater and attached biomass.

Trickling filters, in general, perform better if the feed carbon concentration is below a certain threshold level. This can be achieved by blending the high carbon concentration feed wastewater with an oxygenated and low carbon concentration filter effluent.

Impact of Media Size

The response to organic loading on a trickling filter, in terms of COD removal is sensitive to media size and shape. Results of the Baviaanspoort Pilot Plant project indicated that the smaller media size is more effective than the larger media size. **Figure 6.2(e)** shows the organic removal as a function of organic loading for the two different media sizes.

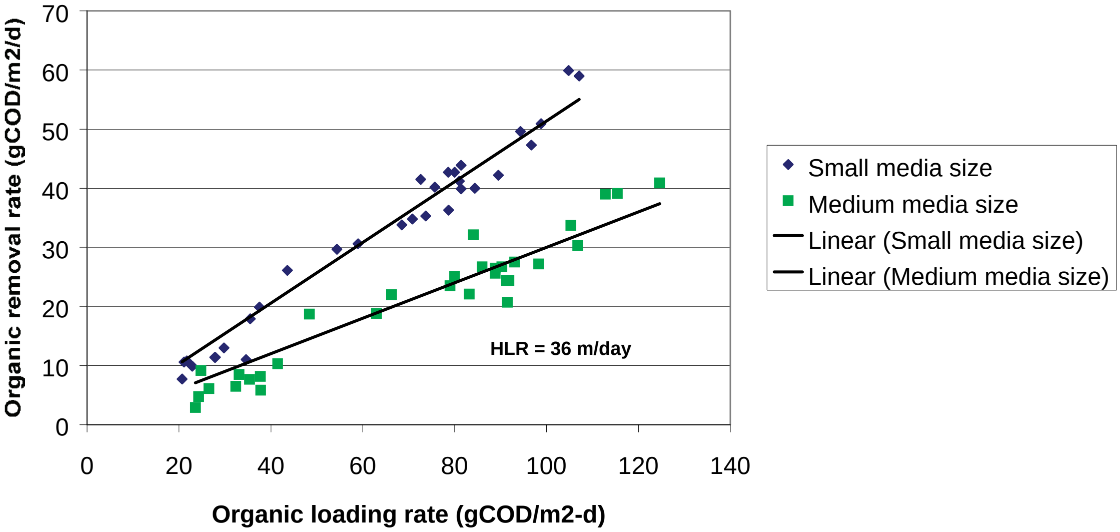


Figure 6.2(e) : Impact of Stone Media Size on Trickling Filter Performance

The smaller media size achieved an average 49 % COD removal, while the larger media size only achieved an average 31 % COD removal. It must be stressed that the better performance of the smaller media size is dependent on effective flushing to maintain an open structure with adequate ventilation.

6.3 Clarification

The performance of a trickling filtration installation is also dependent on the effective separation of the filter effluent suspended solids and the treated effluent. Trickling filter effluent solids may be difficult to separate due to a number of factors:

- The relatively low filter effluent TSS concentration is not amenable to floc formation and rapid settling.

- Anaerobic/anoxic conditions in the filter may result in discharge (sloughing) of fine colloidal solids, which do not settle readily.

- Periodic sloughing/discharge of excess filter solids may result in a variable solids load on the downstream clarifiers.

- Fine colloidal feed solids may migrate through the filter without aggregation with the filter biosolids. Such fine solids will report to the downstream clarifiers and will not readily separate.

Effective filter effluent solids separation requires special attention to the following aspects:

- Promotion of flocculation of smaller solids particles into larger flocs to achieve practical solids separation

- Protection of biosolids flocs against disintegration and floc break-up due to excess turbulence and high levels of mixing intensity.

- Introduction of filter effluent solids into the downstream clarifier in a flocculated state and in a manner that does not create short-circuiting of the clarifier.

- Sufficient retention time in quiescent flow conditions to allow solids separation.

- Settled solids (sludge) removal from the clarifier in a manner which does not re-suspend the solids.

The installation of a flocculation zone/compartment associated with the downstream clarifier is recommended for trickling filtration installation. Several references can be consulted on the design of flocculating bioclarifiers. The main design and operating guidelines for such a flocculation zone/compartment on an existing trickling filtration installation can be quantified by conducting an FSS/DSS test. This test investigates the presence and concentration of flocculated suspended solids (FSS) and dispersed suspended solids (DSS) with and without re-flocculation of the trickling filter effluent suspended solids. Details of the test procedure are available in the literature (IWA, 1997). Briefly the test procedure involves:

- Collection of representative filter effluent samples

- Settling of one sample without assisting flocculation, taking a supernatant sample to determine DSS concentration.

- Flash mixing, slow mixing followed by settling on a separate sample. A supernatant sample is taken to determine the FSS concentration.

Any filter effluent with a DSS > FSS concentration has the potential to be flocculated to enhance settling.

6.4 Temperature Effects

The impact of temperature on trickling filter performance has been controversial. Many different operators and researchers have reported conflicting statements on temperature effects.

The observations regarding temperature effects on trickling are clouded by operating conditions, which result from temperature changes. It is commonly observed that thick biofilms develop during cold weather. This is presumably due to continued carbon metabolism, and slower bacterial respiration and decay rates. The thicker biofilms may, however, result in partial blocking of flow paths in the filter media, poorer ventilation, redirected wastewater flow paths, reduced media wetting etc. These factors all contribute to poorer filter performance. The interpretation of filter performance data, as a function of temperature may be confounded by these secondary process effects.

The commonly used correction of filter reaction rates is based on the expression by Sarner (1978):

$$K_t = K_{20} [\theta_c]^{T-20} \quad \text{......6.4.1}$$

Where K_t = reaction rate at temperature, T
K_{20} = reaction rate at temperature 20°C
T = temperature, °C
θ_c = Arrhenius coefficient
= 1.035

6.5 Solids Production

The solids production from a trickling filter depends on the following factors:

- Composition of the feed in terms of non-volatile suspended solids and non-biodegradable volatile solids.

- Biomass production due to organic carbon metabolism. The biomass associated with nitrogen oxidation (nitrification) is relatively small and is typically not taken into account.

- Chemical precipitate formation, especially if a metal salt is dosed to the trickling filter effluent.

The solids production can be expressed in the following manner:

$$P = IS_o + f\,VS_o + Y_n (S_o - S_e) \quad \text{......6.5.1}$$

where P = solids production (mg/ℓ)
IS_o = feed inert solids concentration (mg/ℓ)
f = non-degradable volatile solids fraction

VS_o = feed volatile solids concentration (mg/ℓ)
Y_n = biosolids nett yield (mg VSS/mg COD removed)
S_o = filter feed COD concentration (mg/ℓ)
S_e = clarified filter effluent COD concentration (mg/ℓ)

The typical parameter range varies for settled domestic sewage:

IS_o = 5 – 15 mg/ℓ
f = 0.03 – 0.1
Y_n = 0.25 – 0.35

Case Study – Sludge Production. Consider a trickling filter receiving a primary effluent flow of 1 500 m^3/day and COD concentration of 370 mg/ℓ, IS_o = 10 mg/ℓ and VS_o = 85 mg/ℓ.

The estimated solids production, based on an 85 % COD removal is as follows:

$$
\begin{aligned}
X_p &= IS_o + f.VS_o + Y_n (S_o - S_e) \\
&= 10 + 0.06 (85) + 0.3 (0.85 \times 370) \\
&= 110 \text{ mg/ℓ}
\end{aligned}
$$

The clarified trickling filter effluent may contain a residual TSS concentration of 15 mg/ℓ. The actual sludge withdrawn from the downstream clarifier is then approximately :

$$
\begin{aligned}
X_p &= 1\,500 (110 - 15)/1\,000 \\
&= 143 \text{ kg TS/day}
\end{aligned}
$$

Case Study: Biomass Distribution in Synthetic Media Trickling Filter. A synthetic media (Terbopac TBX 2 700)filter receives an anaerobic pond effluent flow. The filter has a total depth of 7.2 m and is operated at the following average loading rates:

- Hydraulic loading = 47 m/day
- Organic loading = 975g COD/m^3-day

Figure 6.5 shows the measured biomass concentration as a function of the filter depth.

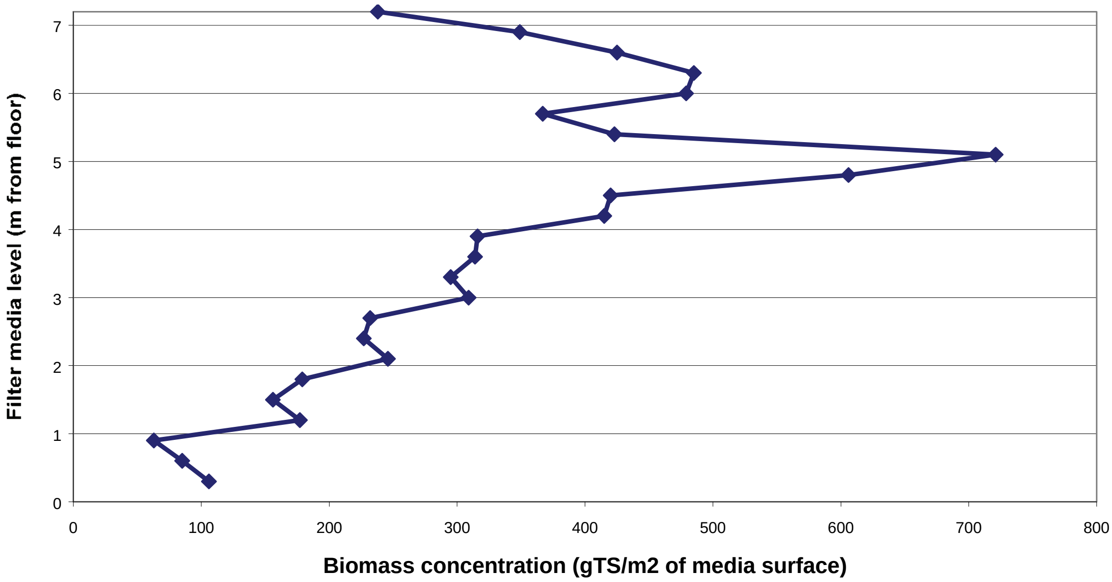


Figure 6.5 : Biomass Distribution in Synthetic Media Filter

The biomass concentration peaks approximate 2 m below the top and then drops off as the feed substrate is depleted. The biomass weight can be as much as four times the dry synthetic media mass.

Chapter 7

7 NITROGEN REMOVAL

Nitrogen removal in trickling filtration systems is achieved by a combination of nitrification (oxidation of ammonia) and denitrification (reduction of nitrite/nitrate). Specific operating conditions are required as a prerequisite for nitrogen removal in trickling filters. The conditions for effective nitrification include :

- Low carbon (BOD/COD) concentrations in the trickling filter to limit the competition between heterotrophic bacteria (fast growing) with autotrophic bacteria (slow growing).
- Sufficient ventilation to provide ample oxygen (refer to Section 4 of this document).
- Adequate wastewater alkalinity to buffer the wastewater in a pH range which is favourable to autotrophic bacterial growth.
- Moderate to high temperatures, since the autotrophic bacteria are sensitive to the low temperatures, resulting in low growth rates.

Denitrification, on the other hand, is a process performed by heterotrophic bacteria and requires the following environmental conditions:

- High carbon (BOD/COD) concentrations in the presence of nitrate oxygen as electron acceptor. The carbon compounds present must be of a biodegradable nature to allow participation in a microbiologically mediated process, such as denitrification.
- Low DO concentrations, which would compete with nitrate as electron acceptor.

7.1 Species of Nitrogen

Understanding the presence of different nitrogen species in the wastewater is important to modelling and prediction of the nitrogen conversion process. In the feed wastewater it is important to distinguish and measure the following nitrogen species:

- Ammonia nitrogen, typically 60 - 80% of the Total Nitrogen in raw domestic wastewater.
- Organic nitrogen, probably in the form of proteins and protein derivatives such as amino acids. These may be present in soluble, colloidal and even particulate form.

- Nitrite/nitrate is typically not present, except in the case of specific industrial effluent contributions.

The main biochemical conversions of nitrogen taking place in the trickling filtration process would be:

- Hydrolysis of complex organic nitrogen species to simpler amino acids and ammonia.
- Oxidation of ammonia (nitrification).
- Reduction of nitrite/nitrate (denitrification).
- Biosynthesis, typically with ammonia, into viable cell mass.

The main nitrogen species in the trickling filter effluent would include :

- Residual ammonia
- Slowly biodegradable organic nitrogen
- Organic nitrogen contained in cell mass
- Nitrite and nitrate.

The different biochemical processes are shown in **Figure 7.1 (a)**.

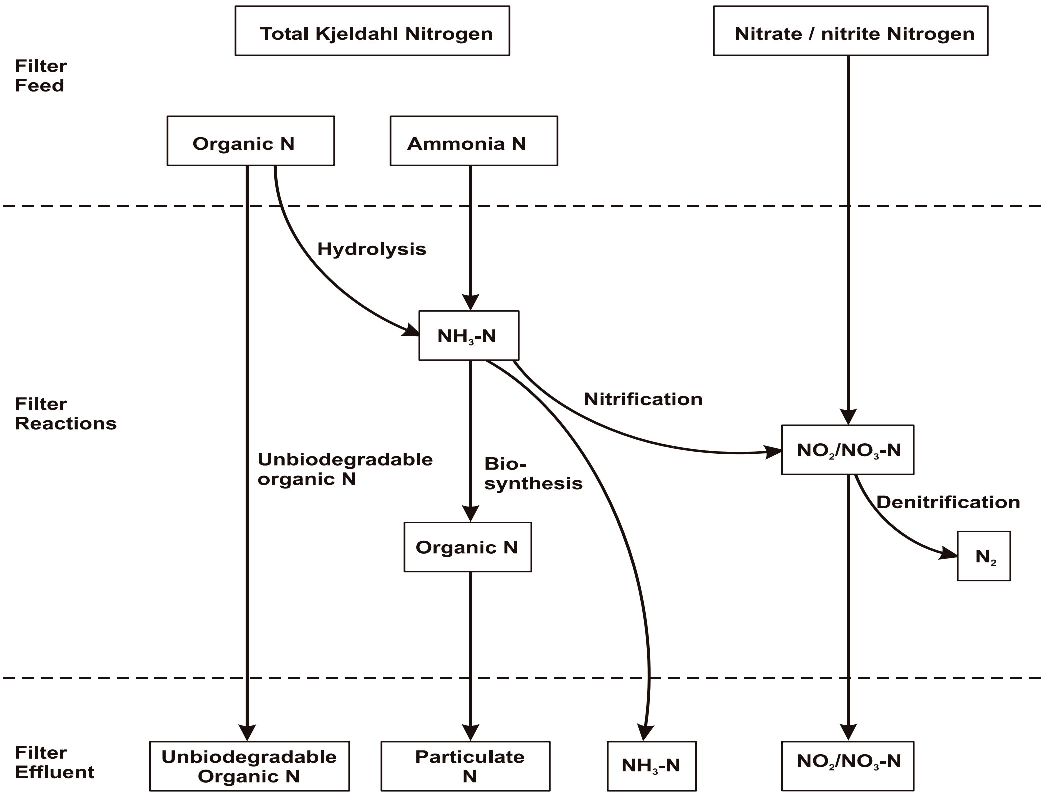


Figure 7.1 (a) : Conversion of Nitrogen Species in Trickling Filters

Many of the nitrogen conversion reactions have an impact on wastewater alkalinity. Alkalinity is very useful as a surrogate parameter to track the conversion of nitrogen species.

Case Study – Nitrogen Conversion as Reflected by Alkalinity Changes. The trickling filter receives a settled wastewater of combined domestic sewage and industrial effluent nature. Monitoring of the plant performance indicated the following filter feed and effluent quality:

- Filter Feed:
  - TKN = 42 mg/ℓ
  - NH_3-N = 9.4 mg/ℓ
  - NO_3-N = 0.9 mg/ℓ
- Filter Effluent:
  - TKN = 23 mg/ℓ
  - NH_3-N = 6.0 mg/ℓ
  - NO_3-N = 6.3 mg/ℓ

Superficial analysis of the results indicates that poor nitrification is achieved, since the NH_3-N concentration only drops from 9.4 mg/ℓ to 6.0 mg/ℓ. A more detailed analysis, however, shows that a substantial fraction of the organic Nitrogen is hydrolysed inside the filter and nitrified in the process. A mass balance reflects the following conversion of Nitrogen:

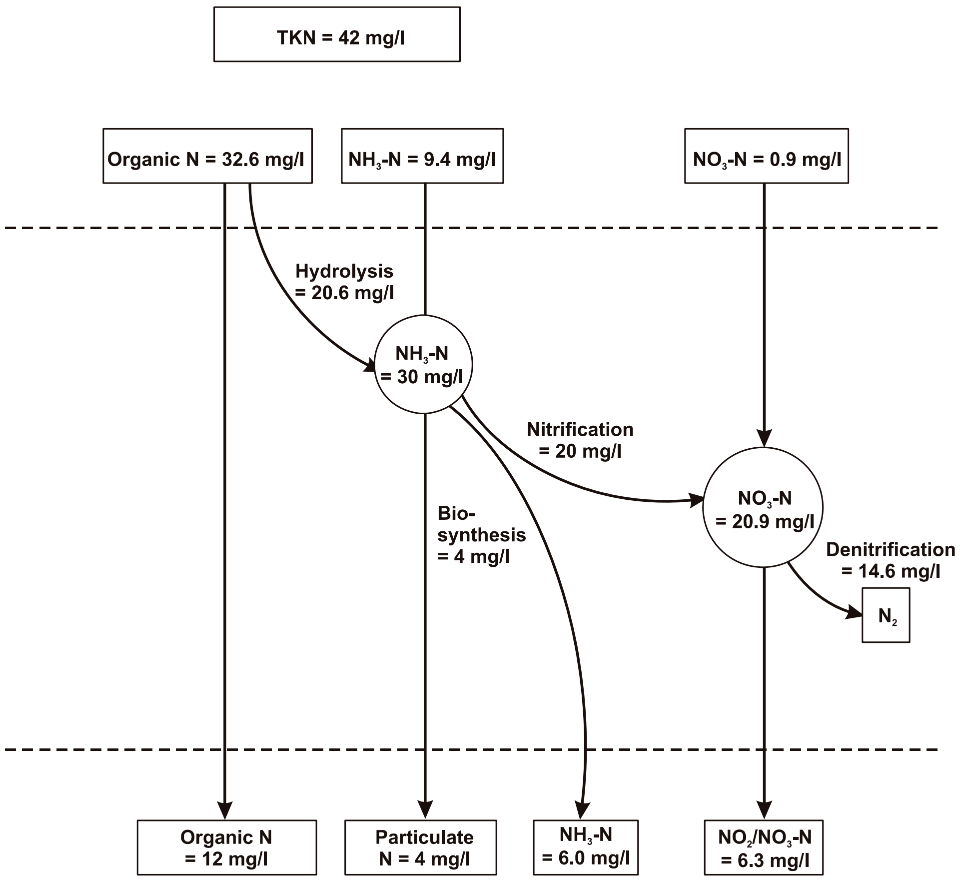


Figure 7.1 (b) : Nitrogen Conversion in a Trickling Filter

The conversion of Nitrogen can be confirmed by calculating the alkalinity changes as follows:

- Organic Nitrogen hydrolysis (ammonification):
  ALK = + 3.57 mg $CaCO_3$/mg N (20.6 mg N/ℓ)
  = + 73 mg/ℓ as $CaCO_3$

- Nitrification of ammonia:
  ALK = - 7.14 mg $CaCO_3$/mg N (20 mg N/ℓ)
  = - 143 mg/ℓ as $CaCO_3$

- Denitrification of nitrate:
  ALK = + 3.57 mg $CaCO_3$/mg N (14.6 mg N/ℓ)
  = + 52 mg/ℓ as $CaCO_3$

The netto loss of alkalinity is then:
= + 73 – 143 + 52
= - 18 mg/ℓ as $CaCO_3$

7.2 Environmental Factors Impacting Nitrogen Removal

Oxygen Concentration

Ammonia oxidation consumes substantial oxygen as reflected by the reaction equation:

$$NH_4^+ + 20_2 \rightarrow NO_3^- + 2H^+ + H_2O \qquad 7.2.1$$

Practically, after allowance for some biosynthesis, nitrification consumes 4.2 to 4.3 kg O_2/kg NH_3-N oxidised.

Nitrification rates are frequently controlled by the availability of oxygen. Okey and Albertson (1989) concluded that oxygen availability is a dominant factor controlling nitrification rates above loading rates of 1.2 g N/m^2-day.

Harremoes et al (1982) concluded that nitrification rates are first order with respect to DO concentrations up to 5 to 6 mg/ℓ and half order with respect to DO concentrations above 5 to 6 mg/ℓ.

An ample supply of oxygen is, therefore, critical to the nitrification process.

Ammonia Concentration

Nitrification rates are also impacted at low NH_3-N concentrations; due to the diffusion and related mass transfer constraints. Okey and Albertson (1989) reported that nitrification rates are first order with respect to ammonia concentrations, when the NH_3-N concentrations drop below 3 to 4 mg/ℓ.

The practical implication is that trickling filter design and operation requires special attention to produce very low residual NH_3-N concentrations in the filter effluent. The viability of nitrifier populations at such low substrate concentrations is also decreased. One approach to enhance nitrification performance, while still achieving low residual NH_3-N concentrations, is to install alternating double filters. The primary filter has excess substrate (NH_3-N) to support a healthy nitrifier biomass, while the polishing filter operates under substrate limitation (low NH_3-N). When a healthy nitrifier population is established on the primary filter, the flow pattern is changed and this healthy filter is employed to conduct the polishing. The original polishing filter is then operated with adequate substrate, giving it an opportunity to recover and build a healthy nitrifier population.

Temperature

The temperature dependence of nitrification in trickling filters is controversial. Observations on the temperature sensitivity is sometimes confounded by aspects such as DO concentrations, NH_3-N concentrations and filter hydrodynamics.

The typical temperature correction expression is:

$$K_{nt} = K_{no} [\theta_n]^{T-20} \quad \text{......} \quad 7.2.2$$

Where K_{nt} = nitrification rate at temperature, T
K_{no} = nitrification rate at 20°C
T = temperature. °C
θ_n = Arrhenius coefficient
= 1.018 – 1.025

7.3 Nitrogen Removal (Nitrification) in the Presence of Carbon Compounds

Numerous researchers have demonstrated that nitrification is suppressed in the presence of biodegradable carbon compounds. The threshold concentration of biodegradable COD, below which nitrification accelerates is typically reported as 30 - 60 mg/ℓ (BOD_5 = 15 – 30mg/ℓ).

The reasons for the limited ability of nitrifiers to compete with the faster growing heterotrophs include :

- Rapid growth in heterotrophic biofilm may cover nitrifier populations, depriving them of access to oxygen.
- Rapid growth and sloughing of heterotrophic bacteria results in a relatively short effective "sludge age" in high rate trickling filters. The nitrifier cell division rate may be too slow to keep up with the cycle of growth and washout resulting in a loss of nitrification.

The dependence of nitrification efficiency on the presence of carbon BOD/COD in the trickling filter is well established. **Figure 7.3** shows the degree of nitrification as a function of the organic loading (g COD/m^3-day) for a number of South African plants.

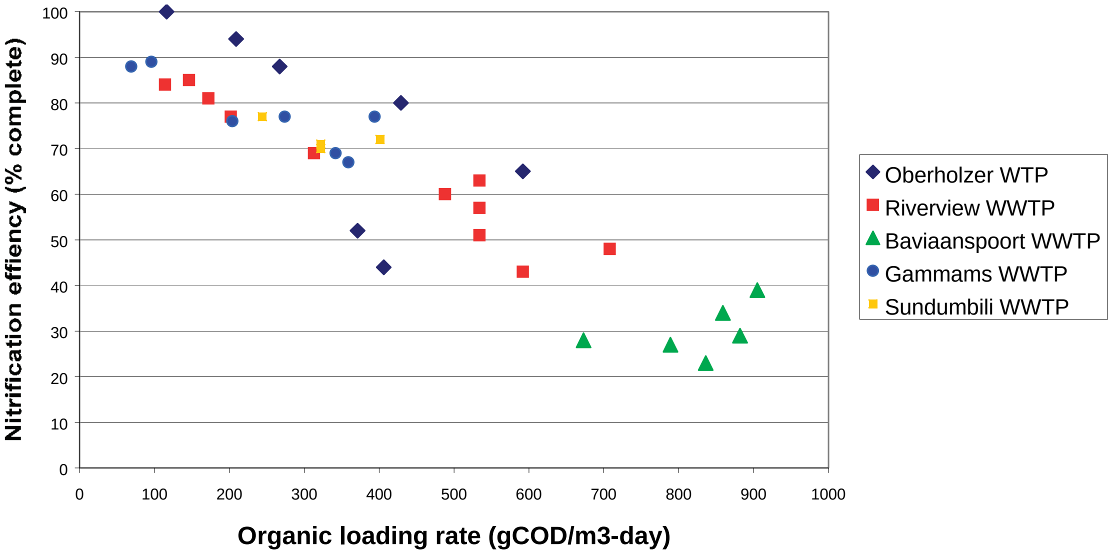


Figure 7.3 : Nitrification Efficiency as a Function of Organic Loading Rate

The South African experience shows that a nitrification efficiency of 80 % requires that the organic loading rate be restricted to 200 – 250 g COD/m^3-day.

Okey and Albertson (1991) proposed the following empirical expression for the calculation of a nitrification rate in the presence of BOD/COD :

$$K_n = 1.086/(BOD_5/TKN)^{-0,44} \quad \text{.......} 7.3.1$$

where K_n = nitrification rate (gN/m^2 per day)
BOD_5 = carbonaceous BOD_5 concentration (mg/ℓ)
= typically 0.5 x COD
TKN = total Kjeldahl nitrogen (mg/ℓ)

7.4 Dedicated Nitrification Filters

Trickling filters can be applied as a tertiary nitrification process, provided that the bulk of the BOD/COD is removed by the upstream processes.

Tertiary nitrification rates are described in terms of a surface related rate :

$$K_n = \exp[0,044(T-10)] \times [N/(N_k-N)] \quad \text{.......} 7.4.1$$

where K_n = nitrification rate (g N/m^2-day)
T = temperature (^{o}C)
N = bulk ammonia nitrogen concentration ($mgNH_3$-N/L)
N_k = half saturation concentration ($mgNH_3$-N/L)
= 1 – 2 mg/ℓ

Parker et al (1989) refined this classical model to account for decreased nitrification efficiency with filter depth.

$$Kn = (E/4.3) \times K_{o,max} \times [N/(N_k + N)] \exp(-rD) \quad \text{.......... 7.4.2}$$

where E = media effectiveness factor
$K_{o,max}$ = maximum oxygen supply rate (g/m^2-day)
= 5.2 gO_2/m^2-day
r = empirical constant
= 0 to 0.16

The first term $E.K_{omax}$ /4.3 is the oxygen limiting term of the maximum nitrification rate and the influence of media effectiveness (E). The second term, $N/(N_k + N)$, corrects for the actual ammonia concentration. The last term, exp (-rD), adjusts the nitrification rate for the decline as a function of filter depth.

Case Study – Sizing of Tertiary Nitrification Trickling Filter. The required sizing of a nitrification trickling filter with the following flow and loading rates:

Flow rate	=	500 m^3/day
Feed NH_3-N	=	32 mg/ℓ
Effluent NH_3-N	=	1.5 mg/ℓ

The required surface area of the filter, based on maintaining a minimum surface hydraulic loading rate of 45 m^3/m^2-day (for synthetic media) is:

$$A = (500\ m^3/day)/(45\ m^3/m^2\text{-day})$$
$$= 11.1\ m^2\ (3.8\ m\ diameter)$$

Select a synthetic filter media with the following properties:

Specific area	=	140 m^2/m^3
Effectiveness, E	=	85 %
Empirical constant, r	=	0.0

In the top part of the filter, nitrification can proceed at the maximum rate of :

$$K_{n,max} = E./4.3 * K_{omax}$$
$$= 0.85/4.3 \times 5.2$$
$$= 1.03\ g\ N/m^2\text{-day}$$

The rate will start to drop when the residual ammonia concentration approaches Nk = 2.0 mg/ℓ. At the bottom of the filter the maximum nitrification rate will drop to:

$$K_n = 1.03\ (N)/(N_k + N)$$
$$= 1.03\ (1.5)/(1.5 + 2)$$
$$= 0.44\ g\ N/m^2\text{-day}$$

A first order estimate of the filter size can be based on the following approach:

- Zero order nitrification rate down to a concentration of three (3) times N_k.

$$V = \frac{500m^3 / day\ x\ (32 - 3\ x\ 2)\ mg/\ell}{1.03gN/m^2 - day\ x\ 140m^2/m^3}$$

$$= 90\ m^3$$

- First order nitrification rate down to the desired effluent ammonia concentration of 1.5 mg N/ℓ

$$V = \frac{500m^3 / day\ x\ (6 - 1.5)\ mg/\ell}{{}^1/_2\ (1.03 + 0.44)\ gN/m^2 - day\ x\ 140m^2/m^3}$$

$$= 22\ m^3$$

The total required filter volume is therefore, 112 m^3. The required filter height would be 10.1 m (or 2 x 5.05 m filters in series).

Chapter 8

8 PRACTICAL APPLICATION ASPECTS

8.1 Filter Shape

Trickling filter shapes are dictated by the rotary distribution mechanisms commonly installed. Filter structures are, therefore, circular, but could also be constructed as hexagonal or octagonal shapes.

8.2 Walls Construction

Natural stone trickling filters require structural walls to contain the filter media. The lateral loads on the walls can be substantial and thermal movement also has to be taken into account. The primary consideration in filter wall construction is therefore of a structural nature.

Filter walls have been constructed using a variety of methods including:

- Reinforced concrete
- Masonry
- Interlocking blocks

The use of interlocking blocks has grown in recent years due to the benefits of using labour-intensive construction techniques, a flexible wall, which can withstand some movement, and an aesthetically pleasing final product. The first known interlocking block filters were constructed in Lydenburg, Mpumalanga Province.

Figure 8.2 (a) shows the original filters constructed at Daspoort, Pretoria using sandstone blocks. **Figure 8.2 (b)** shows a typical modern interlocking block filter.

Figure 8.2 (a): Filter Walls Constructed of Cut Sandstone Blocks

Figure 8.2 (b): Filter Wall Construction Using Interlocking Blocks

Synthetic filter media are typically self-supporting. Walls do not fulfil a structural function, but simply contain the wastewater on the filter.

8.3 Filter Media Supports

Natural stone media filters utilise pre-cast filter blocks. The filter blocks are manufactured from concrete or vitrified clay. Filter blocks must have sufficient openings to allow peak flows and adequate air ventilation without causing submergence of holes. As a guideline, the holes in the filter blocks must be at least 20 % of the plan surface area.

Synthetic media require special support to allow both unobstructed water/air flow and to protect the filter media against crushing. The operational load carried by synthetic media can be several times higher than the media's own mass. Filter media supports consist of cross beams onto which grating is placed. High synthetic media filters may also require intermediate support, depending on the structural strength of the specific media. Wastewater temperature will influence the maximum allowable filter depth, as plastic softens at high temperatures. Synthetic filter media applications for wastewater temperatures in excess of 40°C must be approached with caution. Synthetic media suppliers also offer proprietary support systems.

8.4 Underdrains

The filter floor slopes to either central collection channels or to peripheral collection channels. Access is an important consideration in selecting an underdrain system.

A minimum flow velocity of 0.3 to 0.6 m/sec. must be maintained in the underdrains to prevent solids accumulation. Air ventilation openings for natural draft trickling filters direct air flow via the underdrain system to the filter media. Air ventilation openings should be sized to at least 15 % of the filter cross-sectional area.

8.5 Filter Media Strength

Natural stone media, if sourced and prepared as specified in Section 5, have adequate strength.

Synthetic media, on the other hand, require special consideration in terms of long term strength. Structured synthetic media are fabricated from PVC and the strength will be sensitive to:

- Thickness of material
- Operating temperature
- Age

Synthetic media are fabricated using different plate/sheet thicknesses and this is a primary determinant of structural strength. The spacing of sheets will also influence structural strength. Sheet thickness may be modified during fabrication, especially if corrugation is performed by thermoforming.

PVC starts becoming more pliable as the temperature exceeds 20 - 22 °C. The structural strength has to be confirmed at the maximum operating temperature. Domestic wastewater temperatures may reach a maximum temperature of 25 – 27 °C in summer. Some industrial effluents have much higher temperatures, and PVC media is not recommended for temperatures exceeding 55 °C.

North American (WEF 2001) synthetic media is designed to withstand a long term static load of 290 kg/m^3 media (inclusive of media weight, water retention and attached biogrowth) at maximum operating temperature for 20 years. Short term and long term loading tests have been developed, but these are not routinely applied in South Africa.

Special attention is required to design the synthetic media support system to limit or prevent load conditions, which may result in localised structural failure.

8.6 Distribution Devices

Rotary distributor arms (typically 4 to 6 arms) are utilized to spread the feed wastewater – refer to Section 3.3 of this document.

It is advisable to provide the following features on distribution arms:

- Levelling cables to allow even flow distribution.
- Discharge holes, spaced radialy to ensure even flow distribution.
- End caps with easy access to facility cleaning of the arms.
- Splash plates to spread the feed wastewater.
- Isolation values on each arm to facilitate flushing of the media using only one or two arms.

It has become increasingly popular to install distribution devices with mechanical drives. This feature gives the operator control over the rotational speed and, by implication, the flushing of the filter. Mechanical drives have been installed using a centre-drive or a peripheral drive. A centre drive mechanism can easily be retrofitted to any existing filter as shown in **Figure 8.6**.

Figure 8.6 : Typical Centre Column Mechanical Drive Installation

8.7 Dosing Siphons

The installation of dosing siphons on the feed wastewater stream to hydraulically driven trickling filter installations is recommended. An analysis of the diurnal wastewater flow pattern and minimum threshold flow rate to mobilise the rotating distributor are required to properly size a dosing siphon. Several proprietary dosing siphon mechanisms are available on the market.

Chapter 9

9 ECONOMICS OF TRICKLING FILTRATION

The conventional low rate rock trickling filter installations are considered to be capital intensive. New construction techniques and synthetic filter media may challenge this perception. Many high rate trickling filter applications exist which could be very cost effective in specific situations.

9.1 Capital Investment

The capital construction cost of a trickling filter will be determined by a number of factors.

Geotechnical Conditions

Trickling filters must be constructed on a level and stable earthworks foundation. Differential settlements in the foundation can result in damage to a trickling filter structure. Foundation preparation may therefore require excavation of poor soils and importation and compaction of a suitable founding material.

Floor and Wall Construction

The trickling filter floor is typically constructed using reinforced concrete. A number of alternative construction options exist for rock filter walls including segmented reinforced concrete walls, interlocking blocks, rock filled gabions etc. The construction cost will depend on the local availability and rates for material and labour.

Filter Media

A wide range of natural stone media or synthetic filter media can be considered for different applications. The local availability of a suitable rock media is a constraint in parts of Southern Africa. Transportation cost will then influence the filter media cost.

Synthetic media is usually transported as loose sheets to save on cost. The synthetic media sheets are then assembled and glued on the plant site.

Pumps and Pipework

Some wastewater treatment plant sites have a favourable topography to allow gravity flow through the trickling filters. Trickling filters ideally require a plant site with a substantial gradient, since the hydraulic head loss is equal to the feed flow and effluent flow friction losses as well as the total filter depth.

The feed wastewater may therefore have to be pumped to the trickling filters on a relatively flat site or if the filters are high.

The total installed capital cost for a trickling filter depends on all the above factors. At the current (2002) price indices, the capital cost could vary between R300 – R700 per m^3 of the filter volume.

Synthetic filter media typically cost R500 per m^3 installed, but require less extensive floor and wall construction.

9.2 Operating and Maintenance Costs

The operating and maintenance cost for a total trickling filtration treatment plant will include components to allow for :

- Personnel and labour to undertake the routine operation of the facility.
- Electrical power to drive pumps, filter distributor arms, clarifier bridges etc.
- Chemical dosing, for example a metal salt addition if phosphate removal is required.
- Maintenance and repair of equipment and instrumentation.
- Management and overheads including transport, communication, insurance, safety etc.
- Monitoring, including sampling and analysis of wastewater streams.

Case Study : ERWAT Vlakplaats Wastewater Treatment Plant. ERWAT conducted an evaluation of the operations and maintenance cost associated with the trickling filter facility at Vlakplaats Wastewater Treatment Plant in 1999. The evaluation was for a complete trickling filtration treatment plant including preliminary treatment (screening and grit removal), primary clarification, trickling filtration, chemical dosing for phosphate removal, humus clarification and chlorine disinfection.

The total O&M cost (2002 price levels) associated with the trickling filter treatment plant (excluding sludge handling and disposal) was as follows :

Manpower	=	7,7 c/m^3	treated
Electrical power	=	2,5 c/m^3	treated
Chemical dosing	=	7,8 c/m^3	treated
Plant maintenance	=	2,2 c/m^3	treated
Laboratory services	=	1,7 c/m^3	treated
Total	=	**21,9 c/m^3**	**treated**

References

1. DWAF (1999) Unpublished report on Technology Perspective-Development of Waste Discharge Standards prepared by Wates, Meiring & Barnard with reference 3835/1772/1/W.

2. Droste, R.L. (1997). Theory and Practice of Water and Wastewater Treatment – John Wiley and Sons. p607.

3. Water Environment Federation (2000). Aerobic Fixed – Growth Reactors. Special Publication prepared by Task Force under the direction of Municipal Subcommittee of the Technical Practice Committee.

4. International Water Association (1997) Secondary Settling Tanks : Theory, Modeling, Design and Operation. Scientific and Technical Report No. 6. G.A. Ekama Editor.

5. Okey R.W. and Albertson O.E. CRM and Enviro Enterprises Inc. Salt Lake City, (1991). Communication to Task Force on Nitrification in Dual-Purpose Biotowers.

6. Harremoes P. (1982) Criteria for Nitrification in Fixed Film Reactors. Water Science and Technology. Volume 14. p167.

7. Parker D.S. et al (1989). Enhancing Reaction Rates in Nitrifying Trickling Filters through Biofilm Control. J. Water Pollution Control Federation. Volume 61. p618.

8. Terbo-Pac (2002). Product Information Data obtained from Terbo-Pac, Mr Harry Botha.