INNOQUA

Technical Bulletin 02
August 2019

INNOQUA is demonstrating how nature-based solutions can treat wastewater to a standard at which can be safely discharged back to the environment or used for irrigation purposes. This technical bulletin comprises a mini review of published data on the fundamental operating principles and performance of the Lumbrifilter, also known as a 'vermifilter' or 'microbial-earthworm ecofilter'.

WHAT IS A VERMIFILTER?

Vermifilters are engineered natural systems, based on the interaction between earthworms and microorganisms, in which earthworms degrade and homogenize organic wastes, increasing their surface area and facilitating subsequent bio-chemical degradation of pollutants by the microbial biofilm established on a filter bed (Arora and Kazmi, 2015). Vermifilters have been used to treat blackwater, greywater, primary (settled) sewage and a range of industrial effluents – the treated effluent then being suitable for discharge, reuse or further treatment. These microbial-earthworm ecofilters (MEEs) have been shown to provide more consistent wastewater treatment performance than conventional biofilters that do not include earthworms. They also remove both nutrients and pathogens, and produce little excess sludge (Jiang *et al.*, 2016). Vermifiltration principles have also been applied to the development of 'Tiger Toilets' - a variation on traditional pit latrines in which earthworms consume and stabilise faecal material, dramatically reducing solids' accumulation rates ((Furlong *et al.*, 2016). The INNOQUA lumbrifilters are designed to treat primary (settled) domestic sewage.

BASIC DESIGN CONCEPTS

Vermifiltration systems all follow similar design principles:

1. Filter media are built up in a series of layers – normally of increasing particle size with depth. These layers may be mineral (sand, gravel or man-made equivalents) or organic (compost, bark, sawdust);
2. A distinct uppermost 'bedding' layer is normally included, comprising an organic substrate or an organic-matter rich soil – to suit the requirements of epigeic[1] earthworm species such as *Eisenia fetida*, *Eisenia andrei*, *Perionyx sansibaricus* or *Lumbricus rubellus.* Vegetation is sometimes established in this top layer;
3. Wastewater is introduced to the top of the filter using a distribution system. Wastewater can be introduced as greywater, blackwater or (primary) settled sewage – each of which requires different filter media, depth and operating volume to optimize treatment;
4. Wastewater percolates through the filter bed, where treatment takes place in an established biofilm as it does in aerobic trickling filter systems. Earthworms graze on the microbial biomass and solids introduced in the wastewater – moderating the microbial community and helping to maintain aerobic conditions. The treated effluent collects within the lowest gravel layer or a separate sump, from where it may be collected for discharge, further treatment or re-use;
5. The filter bed requires little maintenance, since a healthy earthworm population will maintain a network of channels throughout the medium. The surface may eventually become clogged with earthworm casts that can be harvested for re-use in agriculture or horticulture;

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[1] Found predominantly on the soil surface in leaf-litter, compost or manure. These species are widely used in vermicomposting

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6. Vermifiltration systems require no external power, although pumps are commonly used to introduce wastewater and/or remove treated effluent in experimental systems. They may be operated as single units, or as multiple units in series – depending on site and wastewater-specific circumstances.

Figure 1 Schematic for a vermifilter, (adapted from Singh, Bhunia and Dash, 2017)

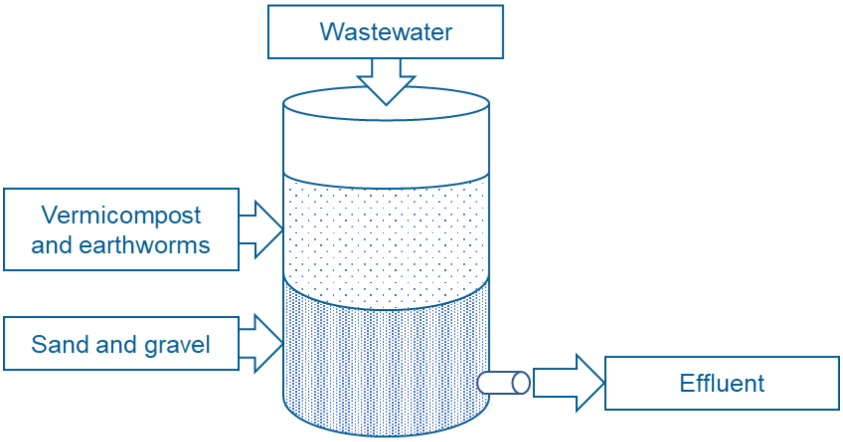
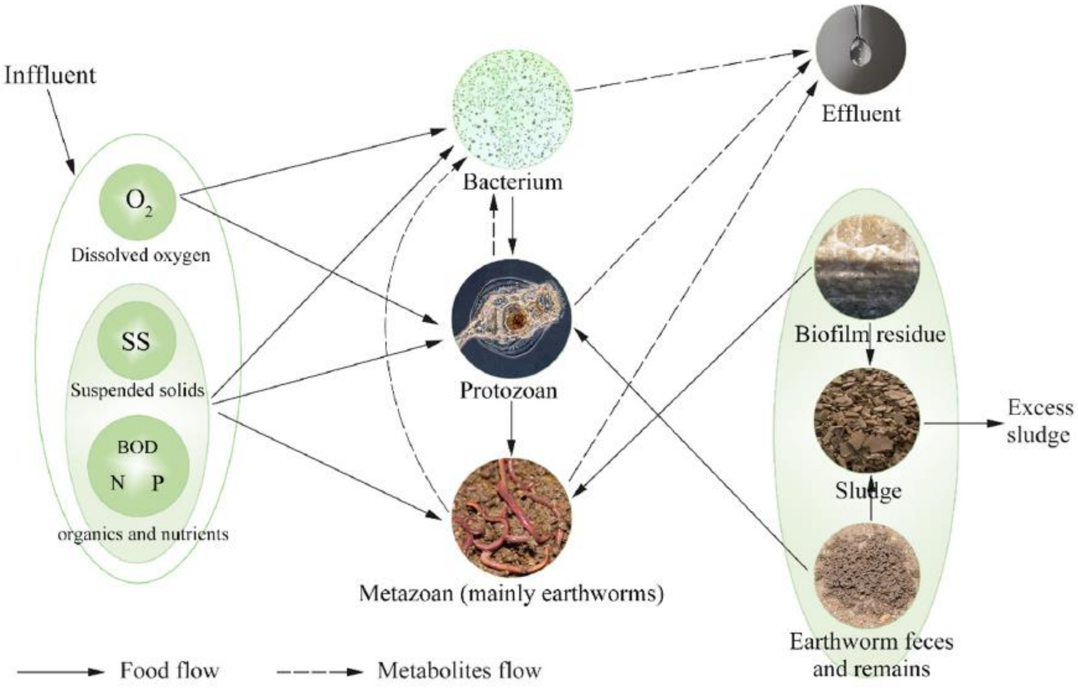


Figure 2 Basic principles of vermifiltration, as set out by Jiang *et al.* (2016)



The bedding material type, filter media type, earthworm species, type of wastewater, temperature, pH, hydraulic loading and other factors can interact to affect the efficiency of the system. Various media have been trialled, including sawdust, coir, bark, woodchips, gravel, glass and clay balls – with variations in the filter bed type and height influencing the distribution of COD. Aerobic-anoxic microenvironments can then form, which impact on nutrient removal efficiencies (Jiang *et al.*, 2016). Vermifiltration has been successfully demonstrated in many countries, including: Burkina Faso (Adugna *et al.*, 2014); India (Arora and Kazmi, 2015); Jordan (Dalahmeh *et al.*, 2011); China (Liu *et al.*, 2012); Portugal (Lourenço and Nunes, 2017); Zimbabwe (Manyuchi, Kadzungura and Boka, 2013); Australia (Sinha, Bharambe and Chaudhari, 2008).

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TREATMENT EFFICACY: NUTRIENTS

Previous studies have examined the treatment efficacy of vermifilters by measuring standard suites of characteristics in wastewater before and after filtration. These suites typically include BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), total phosphorus, total suspended solids (TSS), pH, total nitrogen and ammoniacal nitrogen. High BOD and COD removal rates have been demonstrated (Table 1) – but nutrient removal efficiencies depend very much on the design and operation of the system, as well as the required degree of treatment. Singh, Bhunia and Dash (2017) highlight the potential for filter bed media to be selected with specific phosphorus-adsorbing characteristics, while long HRTs in well-aerated media will improve nitrification (reducing ammonia concentrations in the final effluent). The same authors highlight the influence of feeding regime, with intermittent feeding more likely to allow stable aerobic conditions to develop within the filter bed – reducing potentially harmful ammonia impacts on the earthworms by encouraging nitrification.

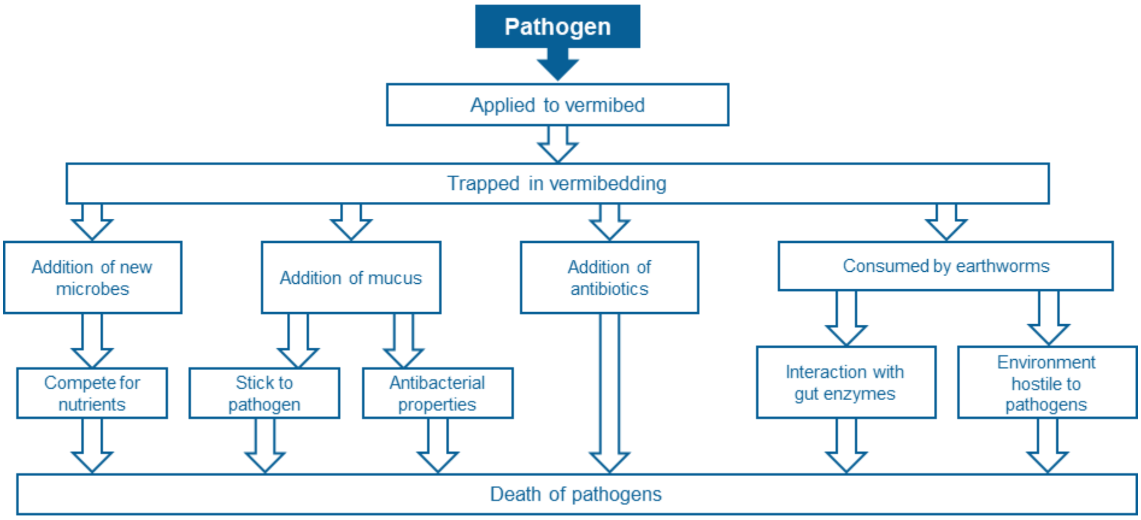
Table 1 BOD and COD removal efficiencies for domestic sewage as previously demonstrated by other authors and summarised in Singh, Bhunia and Dash (2017)

Source	Influent BOD (mg/l)	BOD removal (%)	Influent COD (mg/l)	COD removal (%)
1	240 ± 13	85 – 91	415 ± 18	-
2	330 ± 15	84 – 86	480 ± 21	65 – 80
3	-	54.78 – 66.36	-	47.3 – 64.7
4	121 – 280	96 – 98	190 – 405	94 – 95
5	327 ± 213	96 – 98	472 ± 718	-
6	328 ± 15	80 – 92	448 ± 32	70 – 80
7	14 – 44	54.34 ± 8	40 – 100	40.31 ± 5

TREATMENT EFFICACY: PATHOGENS

Various mechanisms have been proposed for the impact of vermifiltration on pathogens in wastewater, as summarized in Figure 3.

Figure 3 Possible mechanisms for pathogen removal / attenuation during vermifiltration, as set out in Singh, Bhunia and Dash (2017)



It is thought that the reduction of pathogens (faecal coliform, total coliform, faecal streptococci, salmonellae, *E. coli*) is mainly due to the action of enzymes secreted within the intestines of earthworms, and within their secreted mucus (Singh, Bhunia and Dash, 2017). Temperature within the vermifilter is extremely influential on pathogen removal, since it can be directly related to earthworm and microbial activity. Arora and Kazmi (2015) explored

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the seasonal variations in vermifilter efficacy at removing pathogens from a synthetic wastewater inoculated with domestic sewage. Their data are presented in Table 2 for four seasons in the State of Uttarakhand (N India): Winter (December to February, ambient temperature of 15.6 ± 3.3°C), Spring (March to May, ambient temperature of 27.9 ± 5.2 °C), Summer (June to August, ambient temperature of 35.4 ± 3.8 °C) and Autumn (September to November, ambient temperature of 28.5 ± 4.4 °C).

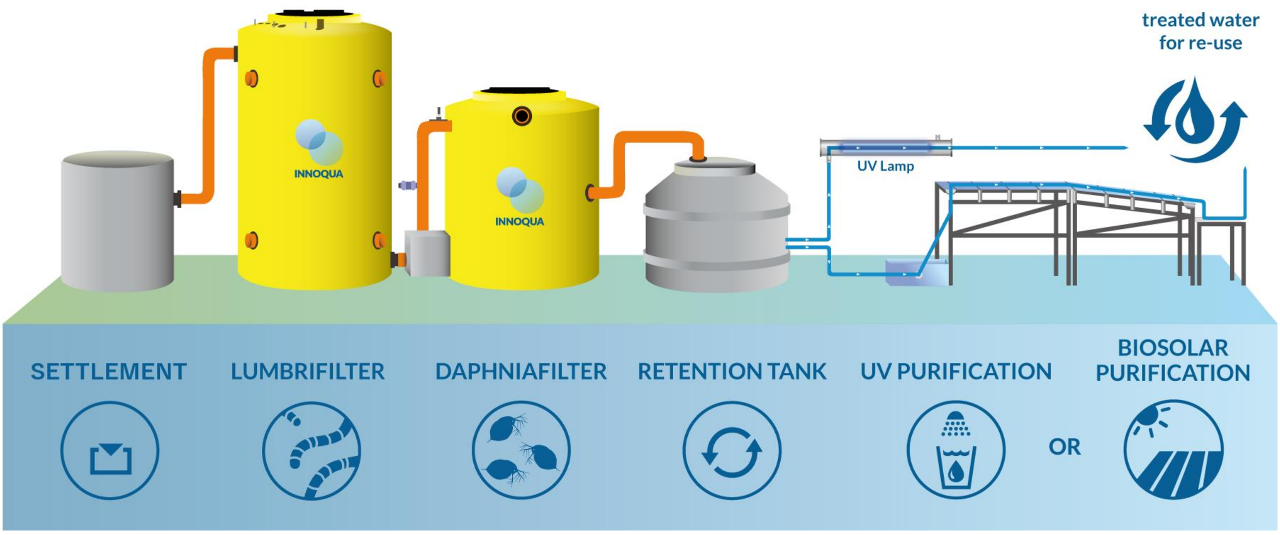
Table 2 Removal efficiencies for various microorganisms across an experimental vermifilter in northern India, showing seasonal variations. Values are means ± standard deviation for 48 samples taken over the period of a year, with four samples per month (from Arora and Kazmi, 2015)

				Removal (%)			
Organisms	unit	Influent	Effluent	Winter	Spring	Summer	Autumn
Total coliforms	$\log_{10}$ MPN / 100ml	6.63 ± 0.60	2.72 ± 1.60	47.80	95.89	98.78	97.69
Faecal coliforms	$\log_{10}$ MPN / 100ml	5.48 ± 0.37	2.66 ± 0.30	52.60	97.12	98.20	80.21
Faecal streptococci	$\log_{10}$ MPN / 100ml	5.45 ± 0.66	2.80 ± 0.50	37.56	95.29	98.60	88.89
E. coli	$\log_{10}$ CFU/ml	4.50 ± 0.42	1.99 ± 0.10	33.93	94.99	99.88	92.32
Salmonella	$\log_{10}$ CFU/ml	3.87 ± 0.94	1.67 ± 0.92	36.07	96.81	96.21	96.51

VERMIFILTER DEMONSTRATION

Vermifilters (referred to as Lumbrifilters within the INNOQUA project) have been installed at demonstration sites in ten countries, to test their performance under different conditions and in combination with other nature-based solutions (Figure 4).

Figure 4 Integration of the Lumbrifilter with other INNOQUA solutions: Daphniafilter, UV purification and Bio-Solar Purification. Vessels may be surface-mounted or partially / completely buried depending on local site conditions and requirements



To date, the INNOQUA technologies have been trialled under controlled conditions at pilot sites in Ireland and Spain. Detailed data have also been captured from replicated bench-scale experiments, which have examined specific issues such as loading rates, reactor bed depths and reactor bed materials. Data from bench and pilot-scale Lumbrifilters are presented in Table 3 and Table 4.

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Table 3 Average removal rates of reactors with different active Lumbrifilter bed depths during steady-state operation: Bench-scale data from the National University of Ireland (Galway)

Depth of active bed layer	n	COD (%)	TSS (%)	TN (%)	TP (%)
700mm*	25	84.0 ± 10.7	65.5 ± 40.7	64.3 ± 11.1	68,4 ± 27.3
1000mm*	25	85.5 ± 5.9	75.1 ± 18.3	63.9 ± 8.3	67.1 ± 16.1
1000mm**	40	71.9 ±3.5	82.8 ±4.2	43.1 ±2.1	98.4 ±0.9
1300mm*	25	82.2 ± 7.3	83.9 ± 10.0	65.9 ±10.2	73.0 ± 12.7
*Samples collected between Day 36 and Day 91 **Samples collected between Day 92 and Day 176					

Table 4 Lumbrifilter influent, effluent and removal efficiencies at a flow rate of 2,400litres per day: Pilot-scale data from the University of Girona

	COD	TSS	NH_4-N
Influent (mg/l)	700 ± 224	552 ± 566	42.2 ± 10.2
Effluent (mg/l)	92.0 ± 40.0	27.5 ± 21.3	4.55 ± 4.64
% removal	85.9 ± 6.56	91.6 ± 10.4	89.1 ± 10.5

VISIT A VERMIFILTER DEMONSTRATION SITE

A series of open days and training events is planned for each site. If you would like to take part or arrange a visit, then please contact the relevant site manager:

Country	Site manager	Contact details
Ecuador	Nicolas Salmon	nsalmon@yes-innovation.com
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In the next technical bulletin, we will explore the potential role of daphnia in wastewater treatment. Further details of the INNOQUA project can be found at www.innoqua-project.eu.

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