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The development of an onsite sanitation system based on vermifiltration: the “Tiger Toilet”

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Abstract

This paper describes the development of a novel onsite sanitation system based on vermifiltration, the Tiger Toilet. Initial laboratory experiments demonstrated that feed distribution was not required, a worm density of 2 kg/m² could be used, worms preferred wetter environments, and system configuration did not affect effluent quality. Installing the first prototype in the UK proved that the process functioned when scaled, i.e. COD and thermotolerant coliform reduction were found to be comparable with the laboratory results. Ten prototypes were then tested by households in rural India; all were working well after six months. The vermifilters were processing the amount of faeces entering the system on a daily basis, so faeces was not accumulating. It was estimated that they would require emptying after approximately five years, based on the depth of the vermicompost generated. With further development it is believed that the Tiger Toilet has the potential to become a superior form of onsite sanitation, when compared with traditional onsite sanitation technologies.

Introduction

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2 The majority of the world's population has little choice in terms of onsite sanitation
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4 technology. Most rely on pit latrines, cesspits and septic tanks. A major problem
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6 associated with these systems is that they require emptying, which can be costly,
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8 inconvenient and hazardous. Approximately 200 million latrines and septic tanks
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10 worldwide must be manually emptied each year, by workers descending into the pit
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12 equipped with buckets and spades (Thye et al., 2011). Furthermore, the final disposal
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14 of faecal sludge by any of these methods is often simply by dumping into the
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16 immediate environment, thereby reintroducing pathogens which were previously
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18 safely contained in the pit or tank. New onsite sanitation technologies need to be
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20 developed which reduce the frequency of emptying and which not only contain, but
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22 also treat the waste, so that handling and disposal are safer activities.
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31 Worm-based sanitation may provide a solution, since solids are further reduced by the
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33 net loss of biomass and energy when the food chain is extended with worms (Xing et
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35 al., 2014). This approach has the potential to reduce both the frequency of emptying
36
37 and the size of the sanitation system. Furthermore, worms have the ability to reduce
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39 pathogens to the level where the by-product (vermicompost) can be safely applied to
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41 land (Eastman et al., 2001). Vermicompost is dry and soil-like, making it easier to
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43 handle and transport.
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52 This paper builds on the findings in Furlong et al. (2014), which is believed to be the
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54 first paper to show that worms are able to efficiently digest and thrive on fresh human
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56 faeces in a wet (flushing) vermifilter (a filter containing worms). Two laboratory
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58 studies are described which explore critical design parameters. These studies led to
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1 the development and testing of the first full-scale prototype. Finally, the results of the
2 first six months of a field trial of the “Tiger Toilet” (a vermifilter paired with a pour-
3 flush pan and superstructure) in rural India are presented.
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9 **Methodology**

10 The species of worms used in the laboratory experiments and the first prototype were
11 *Eisenia fetida*, but the close relative *Eisenia andrei* were used in the field trials in
12 India, due to availability. A worm density of 2 kg/m² was used in all systems
13 described in this paper.
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24 ***Laboratory experiments***

25 A detailed description of the laboratory scale vermifilter components can be found in
26 Furlong et al. (2014). Experiment 1 explored the effect of vermifilter configuration on
27 the processing of waste and effluent quality, the effect of lower worm density and
28 feed distribution. The vermifilter configuration varied from Furlong et al. (2014):
29 Vermifilter 1 (V1) consisted of a bedding layer and sump only. Vermifilter 2 (V2)
30 consisted of a bedding layer, two drainage layers and a sump. Vermifilter 3 (V3)
31 consisted of a bedding layer, a drainage layer, another bedding layer and a sump.
32 Vermifilter 4 (V4) consisted of a bedding layer, drainage layer and a sump (Figure 1).
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48 **Figure 1: Experiment 1 vermifilter configuration**

49 The bedding material used in all vermifilters was a volumetric mixture of 33.3% coir,
50 33.3% woodchip and 33.3% vermicompost, and the drainage layer material was as
51 used previously (Furlong et al., 2014). Human faeces were harvested and the
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1 vermifilters were fed as in Furlong et al. (2014) with the amount specified in Table 1.
2 The exception was V4 where it was spread across the surface to assess feed
3 dispersion. This experiment was split into four phases with different feeding regimes
4 (Table 1). A resting phase was incorporated due to a lack of feed and staff over a
5 holiday period.
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14 Experiment 2 was a continuation of Experiment 1, the modular boxes being
15 rearranged to the configuration in Furlong et al.(2014), and the effect of hydraulic
16 loading was assessed (Table 1). Each vermifilter was fed the same amount, but this
17 amount varied daily.
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26 **Table 1: Details of Experiment 1 and 2**

27 *CAT Prototype*

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32 A full-scale prototype was based at the Centre for Alternative Technology (CAT) in
33 Wales. It was a cylindrical tank with a diameter of 1.2 m and a height of 1.2 meters.
34 Internally there was a 65 cm deep drainage layer (material as in Furlong et al., 2014),
35 and on top of this was a 10 cm bedding layer (as in the laboratory experiments),
36 which was contained by metal mesh. At the bottom there was a tap, so effluent
37 samples could be taken. The prototype vermifilter had an insulated lid and was
38 temperature controlled at 20°C by a heating blanket (to simulate a warmer climate).
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5 ***Indian field trials***
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7 The field trials in India were located in a rural village approximately 60 km from
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9 Pune, in Maharashtra State. Ten households (56 people) were recruited for this trial.
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13 Ten vermifilters were constructed in brick, diameter 1.2 m by 1.25 m deep with an
14 open base. The bedding layer consisted of 10 cm of local compost and the drainage
15 layer (60 cm deep) was graded aggregate, the top layer being sand. The design
16 incorporated an inspection chamber for influent collection and a vertical perforated
17 pipe for effluent collection. The vermifilters were set in the ground and the effluent
18 infiltrated into the soil.
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30 All vermifilters were monitored weekly using structured observations, then five
31 representative vermifilters were monitored monthly. Influent samples were taken
32 monthly by blocking the outlet of the inspection chamber for 24 hours. The sample
33 was then homogenised. Monthly effluent samples were collected via the perforated
34 sample pipe (1.10 m x 10 cm diameter), open at both ends. A collection vessel was
35 placed at the bottom of the pipe to block infiltration into the ground for one week. The
36 effluent sample was allowed to settle before the supernatant was decanted for analysis
37 due to vermicompost being washed into the sample pipe. This ensured the samples
38 collected were representative of the effluent which was being infiltrated into the soil.
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2.2 Methods of analysis

In the laboratory experiments wet mass measurements and calculations were performed as previously (Furlong et al., 2014). Influent and effluent samples were taken approximately weekly from the laboratory experiments and the CAT prototype. These were analysed for COD and thermotolerant coliforms (TTC) as in Furlong et al. (2014). The samples from the Indian prototypes were analysed in a commercial laboratory for COD (5220D, APHA, 1981) and TTC (9222B, APHA, 1981).

Statistical analysis of results was carried out using SPSS 12.0.1. One-way ANOVA was used to compare multiple data sets using the post-hoc Tukey test. The null hypothesis of these tests was accepted if $p \geq 0.05$.

Results and Discussion

The process from laboratory to field took approximately three years.

Laboratory Experiment 1

The total reduction in wet mass of faeces achieved over the course of Experiment 1 (cumulative faecal reduction) was 84-88% (Table 2). No significant difference was found in faecal reduction across the vermifilters. No effect of distributing the waste across the surface of the vermifilter was found, so a dispersal system is not required.

The weekly faecal mass reduction in V4 (worm density of 2 kg/m²) was compared to that from a vermifilter containing the same bedding material from Furlong et al. (2014), which had a higher worm density (4 kg/m²). A difference was found until week five, then the impact of using a lower worm density decreased. Suggesting a

1 worm density of 2 kg/m² could be used as long as the lag phase (4-5 weeks) was
2 engineered into the system. No significant difference was found in the COD or TTC
3 reduction across all the vermifilters. This suggests that treatment of effluent was
4 through the separation of faecal matter by the bedding layer, rather than through
5 treatment in the subsequent layers.
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11 ***Laboratory Experiment 2***

12 No significant difference in effluent quality or the processing of faeces was found
13 across the vermifilters. This suggests that the worms are able to process faeces under
14 both wet and dry conditions. Mass reduction under drier conditions may include the
15 effects of, drying of faecal material as well as processing by the worms. When the
16 vermifilters were decommissioned the vermicompost produced ranged from 1.9 to 3.9
17 kg (Table 1). The lowest production was in V4 which supports this interpretation. V4
18 contained more flies, the surface of the faeces was covered in fungus and it smelt
19 anaerobic. The worm densities at the end of this experiment can be seen in Table 1.
20 Higher final worm densities were associated with higher hydraulic loading,
21 supporting the theory that *E. fetida* prefer wetter environments (Furlong et al., 2014).
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43 **Table 2: Results from different vermifilter studies including; COD and** 44 **thermotolerant coliform reduction, cumulative faecal reduction and** 45 **bioconversion ratios**

46 ***CAT Prototype***

47 From Table 2 it can be seen that the reduction in COD and TTC was comparable with
48 the laboratory experiments. During the 210 days of monitoring the system was found
49 to work well, with no visible faecal overloading of the vermifilter. The system was
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1 designed for 10 users, which was found to equate to two visits for urination only and
2 three for urination and defecation per day, so it could be said that the system was
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4 under used.
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9 *Indian field trials*

10 It was estimated that during six months 216 kg of faecal matter had entered each
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12 vermifilter (based on six people producing 200g of faecal matter per day, over six
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14 months). If undigested this would cover the system to a depth of 21.6 cm. The actual
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16 faecal accumulation over six months was estimated (by observations of coverage and
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18 depth of faeces) to be between 0.2 and 4.5 kg (mean 1.5 kg). In four of the toilets it
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20 was \leq 1kg, which shows that the worms were processing daily the amount of faeces
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22 entering the vermifilters.
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31 Vermicompost started to accumulate within two weeks of use, which was quicker
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33 than in the laboratory experiments and the CAT prototype. This was thought to be
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35 because of the higher temperatures in the India prototypes (20 to 41°C), which
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37 hastens the worms' metabolism. The vermicompost accumulated around the edge of
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39 the faeces and was then pushed to the sides of the vermifilters. This means that the
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41 users will be able to empty the system relatively easily. Over the six month period a
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43 depth of between <1 and 3 cm of vermicompost accumulated, which means the
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45 vermifilters will only require emptying after five years. The worms themselves were
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47 found to be elusive and were only seen in two of the vermifilters. This is quite normal
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49 as worms feed from beneath. A lack of accumulation of faeces together with the
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51 build-up of vermicompost indicates that the worms are present and processing faeces.
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1 The reduction of COD and TTC was lower in the Indian prototypes compared to the
2 CAT prototype (Table 2). This was due to lower levels in the influent of the
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4 vermifilters in India (Table 2). When this was explored it was found that up to 15
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6 litres of water was being used per person per day to flush the systems in India
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8 compared to only five litres used per person per day at CAT. A comparison of the
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10 effluent COD and TTC reveals in absolute terms the effluent quality from the Indian
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12 vermifilters is higher than for the CAT prototype (Table 2).
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19 **Conclusions**

20 This paper describes the journey of developing a vermifilter as a form of onsite
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22 sanitation from laboratory experiment through to field trials. The laboratory
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24 experiments honed critical design criteria which were then incorporated into the first
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26 full-scale prototype. As this functioned as expected the process advanced to field
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28 trials in rural Indian households. This study shows that the Tiger Toilets (vermifilter
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30 paired with a pour-flush toilet pan and superstructure) have been operating
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32 successfully in *real-life* situations for six months. The Tiger Toilet has the potential to
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34 be superior to conventional technology as it provides users with the aspirational
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36 benefits of a septic tank, a smaller footprint and better treatment of waste. Due to the
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38 characteristics of the by-product (vermicompost) and where it is deposited in the
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40 system, many of the problems associated with emptying traditional onsite sanitation
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42 systems are also overcome.
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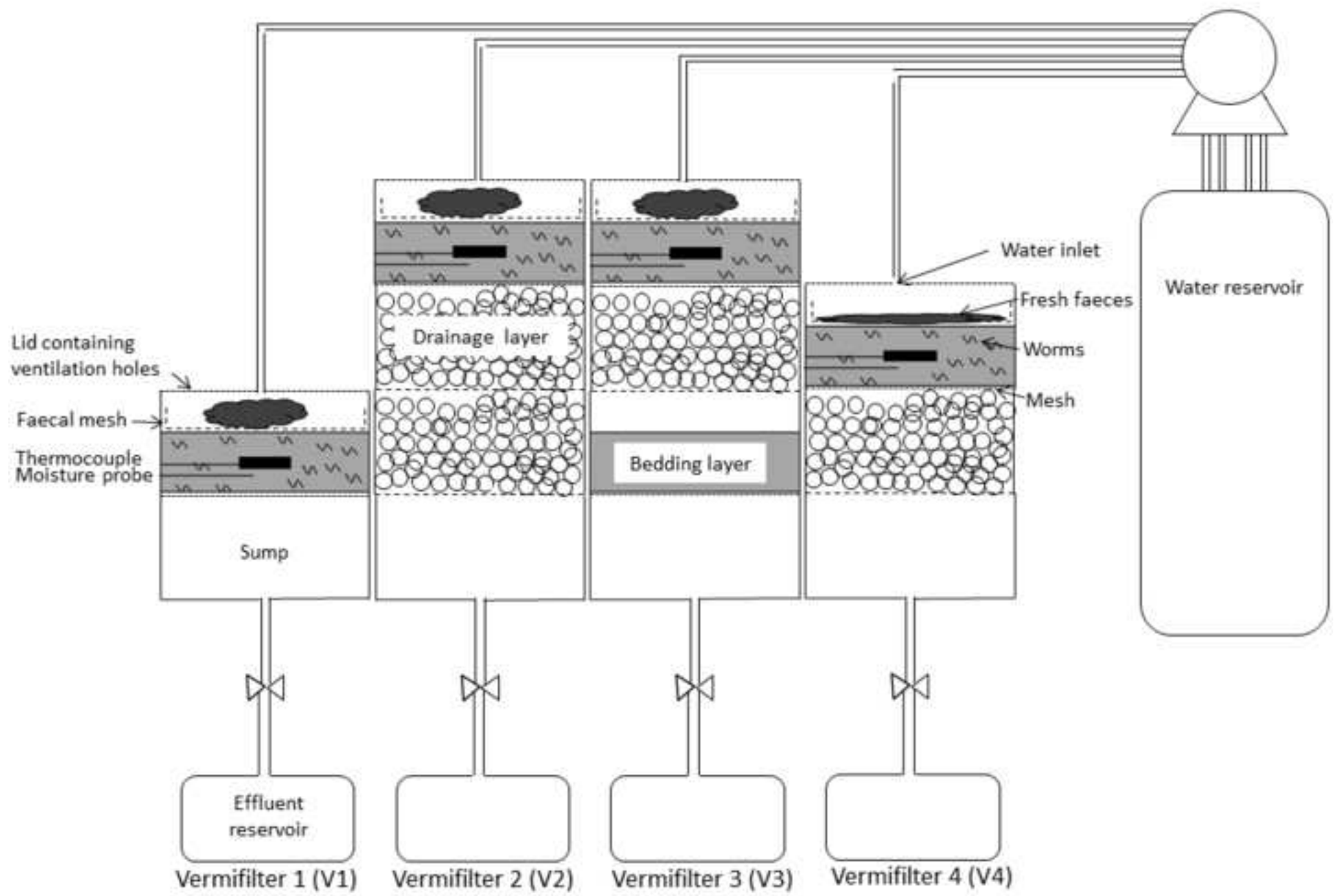
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Experiment 1 (186 days)					Experiment 2 (123 days)				
Phase	Phase description	Period (days)	Hydraulic loading (l/day)	Mean faeces addition (g/day)	Vermifilter	Hydraulic loading (l/day)	Mean faeces addition (g/day)	Final vermicompost weight (kg)	Final worm density (kg/m ²)
1	50 g feed	1-30	12	45 ±15	1	30	157 ±45	3.2	11.8
2	100 g feed	31-47	12	97 ±1	2	12	157 ±46	3.9	11.3
3	Resting phase	48-71	1	0	3	1	155 ±46	3.9	8.3
4	Variable phase	72-186	12	99 ±66	4	0	158 ±46	1.9	8.0

Note: all masses are expressed as wet weights

Experiment	Mean across all vermifilters and phases						Cumulative faecal reduction ¹ (%)	Conversion ratio ²
	COD			TCC				
	Influent (mg/L)	Effluent (mg/L)	Reduction (%)	Influent (CFU/100ml)	Effluent (CFU/100ml)	Reduction (%)		
Furlong et al., (2014) (360 days)	4,666 ³ ±2,848 (n=35)	602 ±326 (n=144)	87	1.03 x 10 ⁹ ±1.01 x 10 ⁹ (n=18)	2.13 x 10 ⁶ ±6.12 x 10 ⁶ (n=72)	2-log ₁₀	97-100	1:0.10-0.18
Experiment 1 (186 days)	6,000 ³ ±8,032 (n=17)	456 ±283 (n=68)	88	1.02 x 10 ⁹ ±1.08 x 10 ⁹ (n=9)	1.23 x 10 ⁶ ±1.71 x 10 ⁶ (n=36)	3-log ₁₀	84-88	-
Experiment 2 (123 days)	5,492 ^{3,4} ±5,358 (n=13)	719 ±363 (n=49)	90	9.02 x 10 ⁸ ±1.31 x 10 ⁹ (n=10)	1.48 x 10 ⁶ ±1.48 x 10 ⁶ (n=38)	3-log ₁₀	80-83	1:0.09-0.19
CAT Prototype (210 days)	14,985 ³ ±2,315 (n=9)	830 ±325 (n=20)	94	8.12 x 10 ⁸ ±9.90 x 10 ⁸ (n=5)	1.84 x 10 ⁶ ±1.98 x 10 ⁶ (n=17)	3-log ₁₀	-	-
Field systems (180 days)	309 ±87 (n=23)	167 ±63 (n=9)	44	5.97 x 10 ⁵ ±2.22 x 10 ⁵ (n=9)	1.70 x 10 ³ ±6.02 x 10 ² (n=9)	2-log ₁₀	98-100	-

¹ Reduction in the total wet mass of faeces that was added over the course of the experiment (Furlong et al., 2014)

² Total kg of faeces added: kg vermicompost harvested at the end of the experiment (Furlong et al., 2014)

³ Influent was a suspension of the average daily mass of faeces over a week suspended in 12L of water

⁴ Only one concentration of influent was analysed