# AQUATIC WORMS FOR SLUDGE REDUCTION

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## ABSTRACT

Several techniques are available for reducing the amount of waste sludge produced at waste water treatment plants. Physical, chemical and mechanical techniques involve a large input of energy and / or chemicals, and may therefore be costly and not sustainable. A biological approach involves the aquatic worm *Lumbriculus variegatus*. The initial experiments with these worms showed promising results. In addition to a reduction in the amount of solids, we also obtained an end product (worm faeces) with better settling properties and a potentially valuable product in the form of protein-rich worm biomass. In the proposed reactor concept, the worms are immobilised in a mesh, which also acts as a separation between waste sludge and worm faeces. To test the applicability of the reactor concept, experiments were performed in which the worms were fed with different types of sludge. Two sludges were obtained from municipal waste water treatment plants, two others were from a lab scale MBR and a lab scale activated sludge reactor. The reduction in total suspended solids ranged from 12 to 40 %. This shows that the nutritious value of waste sludge for the worms varies with the source of the sludge; an important factor for the applicability of our process. From the current experiments we estimated the required size of a worm reactor to be 150 – 860 m$^3$ per tonne of dry solids per day.

## KEY WORDS

Waste sludge, Aquatic worms, Sludge reduction, Sludge type

## INTRODUCTION

Disposal of biological waste sludge produced at waste water treatment plants (WWTPs) is increasingly done by incineration. This is preceded by thickening, dewatering and drying of the waste sludge. Particularly at small WWTPs, where the sludge is usually transported to central sludge treatment facilities, the costs for the initial thickening and dewatering can represent up to 50% of the operational costs [Wei *et al.*, 2003]. This has led to an increased interest in techniques to reduce to amount of waste sludge produced at a WWTP. Several chemical, physical and mechanical techniques are available to disintegrate the sludge and return the lysis products to the WWTP, thereby decreasing the overall sludge production [Wei *et al.*, 2003]. These techniques, however, require a substantial input of energy and/or chemicals and may therefore not be sustainable. Biological approaches include the use of aquatic worms, which extends the food chain and will lead to a lower overall biosolids yield. Several attempts have been made to stimulate the growth of worms that are naturally present in the sludge, though it has proven difficult to promote and sustain high amounts of these worms in the WWTP [Elissen *et al.*, 2008].

Recently was introduced a new reactor concept (Figure 1) in which the aquatic worm *Lumbriculus variegatus* consumes the waste sludge in a separate reactor [Elissen *et al.*, 2006]. The worms consume waste sludge from one side of a carrier material, whilst their tails protrude through this material to take up oxygen on the other side. Part of waste sludge is digested by the worms whilst the remaining solids are compacted into worm faeces.

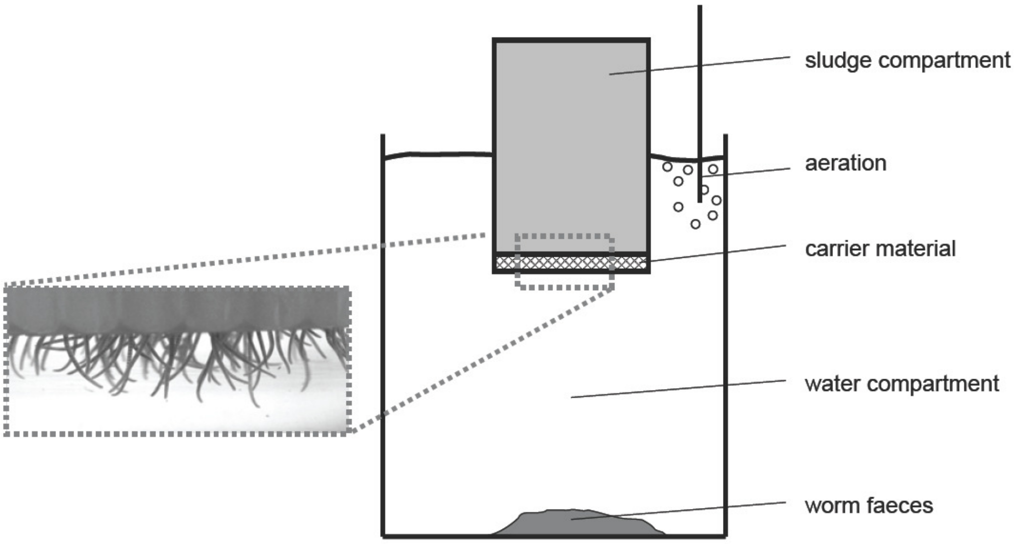

**Figure 1:** **Reactor concept for sludge reduction using the aquatic worm *Lumbriculus variegatus***

This paper describes the experiments performed to test the applicability of this reactor concept to different types of sludge. For this, sludges from two lab scale installations (a conventional activated sludge system and an MBR system) and two municipal WWTPs were used. The improvement in sludge volume index (SVI), reduction in the amount of total suspended solids (TSS) and required size of a worm reactor are discussed.

## MATERIALS AND METHODS

Sludges from four differing installations were used for the experiments: two municipal WWTPs in The Netherlands (Leeuwarden and Bennekom) and two installations operated in the lab: a conventional activated sludge (AS) system and a membrane bioreactor (MBR) system. Characteristics of the installations are shown in Table 1.

**Table 1:** **Details of the installations from where the sludges were obtained**

| | Lab AS | Lab MBR | Bennekom WWTP | Leeuwarden WWTP |
|---|---|---|---|---|
| p.e. (COD based) | 0.06 | 0.12 | 20 000 | 190 000 |
| Denitrification | no | yes | Yes | yes |
| P-removal | no | no | Biological | Biological + Chemical |
| SRT (d) | 29 | 50 | 40 | 25 |

Experiments were performed as described in Elissen *et al.* [2006], using the set-up shown in Figure 1. In short, sludge and worms were put in the sludge compartment, which was sealed with a mesh material (SEFAR, 300 or 350 µm pore size) acting as a carrier material for the worms. The sludge compartment was placed in the water compartment with the carrier material facing down. Within a few minutes the worms protruded their tails through the mesh to take up oxygen from the aerated water compartment. This way, faeces were collected in the water compartment. At the end of an experiment, the amount of faeces and the amount of sludge remaining in the sludge compartment were determined. Parallel to the experiment with the worms, a blank experiment was run to quantify the natural breakdown of the sludge. The amounts of sludge consumed and digested by the worms were calculated as shown in Figure 2.

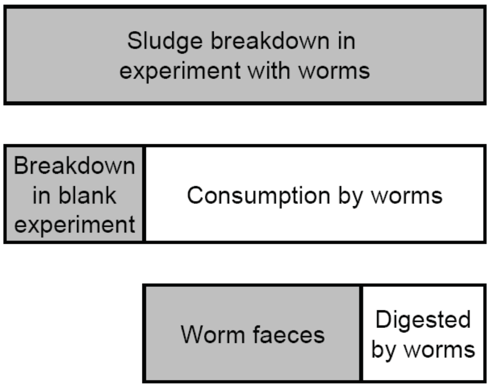

**Figure 2:** **Measured (grey) and calculated (white) amounts of TSS in an experiment**.

The TSS reduction equals the percentage of the TSS consumption that is digested by the worms. For each type of sludge, effluent (or permeate) from the same installation was used in the water compartment.

Analyses were performed according to Standard Methods [APHA, 1998]. Sludge volume index (SVI) was measured using glass 500 or 100 mL graduated cylinders. Black ribbon filters (12-25 µm, Schleicher and Schuell) were used for total and volatile suspended solids (TSS and VSS) measurements. Total nitrogen and total phosphorus in the sludge were determined using Dr Lange® test kits.

## RESULTS

### SVI improvement

Figure 3 shows that for all four types of sludge, the SVI of the worm faeces was about a factor 2 lower than the waste sludge. The improved SVI can be explained by the difference in morphology of the solids between waste sludge and worm faeces, as shown in Figure 4. In contrast to the floccous solids in sludge, the worm faeces are cylindrical and compact. A lower SVI for the worm faeces will result in a higher solids concentration for further sludge thickening operations, which can thus be expected to require less energy.

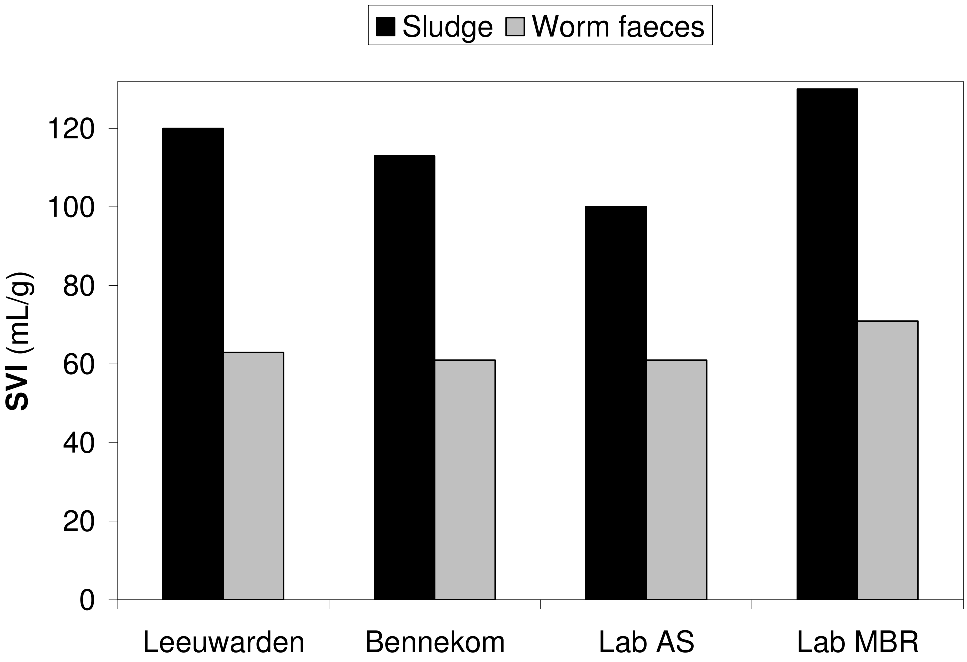

**Figure 3:** **Comparison of the SVI of sludge and worm faeces for the four types of sludge.**

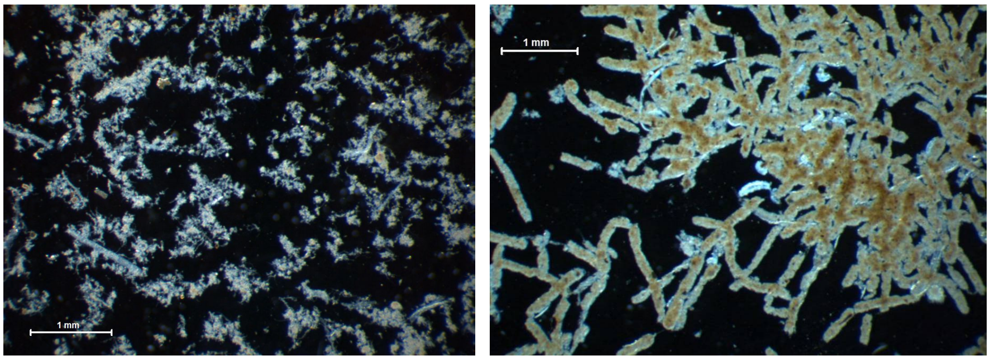

**Figure 4:** **Images of the waste sludge (left) and the worm faeces (right). Scale bar is 1 mm.**

### TSS reduction

The reduction in TSS was measured for all four sludges. As can be seen from Table 2, TSS reduction is not the same for all types of sludge. As it is known that this worm digests mainly the organic part of the sludge (Elissen, 2007), the organic fractions (VSS/TSS) of the sludges are also given in Table 2. A higher organic fraction did, however, not necessarily lead to higher TSS reduction. We further looked at the nitrogen and phosphorus contents of the sludge. As the worm contains a lot of nitrogen (~10 wt%) and 1.5 wt% phosphorus [Hansen *et al.*, 2004], the content of these nutrients in the sludge could be indicative for achievable TSS reduction, though the results in Table 2 show that this is not the case. A more detailed study could try to link e.g. the readily available nitrogen and phosphorus to TSS reduction, but this was outside the scope of the current study. The main outcome of the current study was that all sludges were a suitable substrate for the worms.

**Table 2:** **TSS reduction and sludge compositions for the four types of sludge**

| | | **Lab AS** | **Lab MBR** | **Bennekom** | **Leeuwarden** |
|---|---|---|---|---|---|
| TSS reduction | % | 15 | 12 | 40 | 31 |
| Organic fraction | VSS/TSS | 0.70 | 0.77 | 0.73 | 0.61 |
| Nitrogen content | mg N / g TSS | 80 | 65 | 87 | 60 |
| Phosphorus content | mg P / g TSS | 16 | 21 | 16 | 30 |

### Consumption rate

For each of the sludges, the rate at which the worms consumed the sludge was determined (Table 3), which allowed us to estimate the size of a worm reactor that is required to deal with the daily waste sludge production of a WWTP. It should be noted that higher amounts of worms per $m^2$ of carrier material might be feasible (and thus a lower required surface area per tonne of sludge), this is currently being tested in additional experiments.

**Table 3:** **Sludge consumption rate and estimates for the size of a worm reactor treating different types of sludge. Reactor volume was estimated using 25 $m^2$ of carrier material per $m^3$ of reactor volume**

| | **Consumption rate** kg TSS / ($m^2 \cdot d$) | **Required carrier area** $m^2$ per tonne dry solids per day | **Reactor volume** $m^3$ / tonne dry solids per day |
|---|---|---|---|
| Lab sludge | 0.087 | 11 500 | 460 |
| MBR sludge | 0.27 | 3 750 | 150 |
| Bennekom sludge | 0.046 | 21 500 | 860 |
| Leeuwarden sludge | 0.084 | 12 000 | 480 |

## DISCUSSION

The experiments showed that TSS reduction using aquatic worms is applicable to differing types of sludge, though in some cases the reduction percentage is low. In all cases the SVI of the new waste solids (the worm faeces) was about half that of the initial waste sludge. This will be beneficial to further sludge dewatering operations, as the bulk of the water is easier removed when compared to the waste sludge.

The economic feasibility of a worm reactor will depend on the costs of an additional reactor and the savings made by having less waste solids with better settling characteristics. Particularly at smaller waste water treatment plant this can be expected to have a large impact, as waste sludge is generally transported over long distances to central sludge processing facilities. The additional costs of a worm reactor include construction and operation of the reactor, but also the supply of oxygen to the worms and treatment of the sludge mineralization products released by the worms. The impact of these latter two factors is yet to be determined. An additional benefit of a worm reactor is that part of the waste sludge is converted into potentially valuable worm biomass, which will have a positive contribution towards the economic feasibility. The worm biomass yield on waste sludge and potential markets of the worm biomass are currently being investigated.

So far, small scale and short-term batch experiments have been performed to show the feasibility of a worm reactor. To allow upscale of the worm process, the feasibility in continuously operated reactors needs to be tested in the lab, which will also show the robustness of the process. Furthermore, pilot testing should be performed at a WWTP to assess the possibility to operate under the varying conditions at a WWTP (e.g. temperature, variations in loading rate, etc.).

## CONCLUSIONS

1. The aquatic worm *Lumbriculus variegatus* can be used for reducing the amount of different types of sludge, though the TSS reduction percentage varied and was in some cases low.
2. In all cases, waste sludge was converted to compact worm faeces, with an SVI of about half that of the waste sludge.
3. Based on the current results, the required size of the worm reactor to treat the waste sludge depends on the type of sludge and ranges from 150 to 860 $m^3$ reactor volume per tonne of dry solids per day.

## ACKNOWLEDGEMENTS

We would like to thank Ana Sofia Castro César from Minho University in Braga (Portugal) for her valuable contribution towards performing the experiments. We would also like to thank the operators of the Leeuwarden WWTP and Bennekom WWTP for their assistance in obtaining the sludge and effluent used in the experiments.

## REFERENCES

Elissen, H.J.H., Hendrickx, T.L.G., Temmink, H., Buisman, C.J.N. (2006). A new reactor concept for sludge reduction using aquatic worms. *Wat. Res.*, **40**, 3713-3718.

Elissen, H.J.H., Peters, E.T.H.M., Buys, B.R., Klapwijk, A. and Rulkens, W. (2008). Population dynamics of free-swimming Annelida in four Dutch wastewater treatment plants in relation to process characteristics. *Hydrobiologia*, **605**, 131-142.

Wei, Y., Houten, R. T. van, Borger, A. R., Eikelboom, D. H. and Fan, Y. (2003). Minimization of excess sludge production for biological wastewater treatment. *Wat.Res.*, **37**, 4453-4467.

Hansen, J.A., Lipton, J., Welsh, P.G., Cacela, D., MacConnell, B., 2004. Reduced growth of rainbow trout (Oncorhynchus mykiss) fed a live invertebrate diet pre-exposed to metal-contaminated sediments. Environ. Toxicol. Chem. 23 (8), 1902–1911.

APHA, 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, DC.