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Version 2

Sandec Department of Sanitation, Water and Solid Waste for Development

Piloting a small-footprint wastewater dewatering unit for non-sewered sanitation

Nearly half of the world's population uses toilets that are not connected to a sewer system. Treating the wastewater is challenging, especially in cities where space is limited. One key treatment step is separating out the excess water. Existing methods to do this, however, often require large equipment and a large footprint.

Researchers at Eawag have been testing an innovative way to take out the excess water from the wastewater, a process called 'dewatering'. This testing takes place in the Water Hub, a real-world testing site inside the innovative NEST Building.

System Highlights

- Fully automated dewatering of blackwater
- Small-scale screw press designed for mass production
- In-line dosing of flocculants
- Real-time sensing of blackwater characteristics with low- and high-cost sensors
- Opportunities for more efficient treatment that enable resource recovery
- Modular design of all treatment steps
- The small-footprint system aligns with the limited available space

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Context

The wastewater that comes from toilets is also known as blackwater. It consists of excreta (urine and feces), flushwater, and cleansing materials.

Nearly half the world relies on non-sewered sanitation, where blackwater is treated on-site or transported by road to treatment. Despite their benefits to human and environmental health, sewered systems cannot be built everywhere, because of their high cost and reliance on huge amounts of water and energy to function. Non-sewered systems can be more sustainable and climate-resilient, and enable resource recovery and water reuse through decentralized, modular designs. In non-sewered systems, separating the solids from the water (dewatering) is essential to completely treat the blackwater [1].

System design

As illustrated in **Figures 1** and **2**, the dewatering treatment chain includes a buffer tank, flocculation tank, and screw press. The NEST building unit is treating blackwater from flush toilets, which are used by visitors, employees and residents.

A macerator pump homogenizes the blackwater and conveys it past turbidity sensors to the flocculation tank. Automatic dosing of the flocculant is controlled by turbidity-based solids measurements. Dedicated valves allow for decantation after flocculation and settling. The flocculated blackwater is fed to the screw press, where solid and liquid fractions are separated.

Flocculation is a process in wastewater treatment where chemicals (**flocculants**) help particles in the water stick together into larger clumps, making them easier to remove.

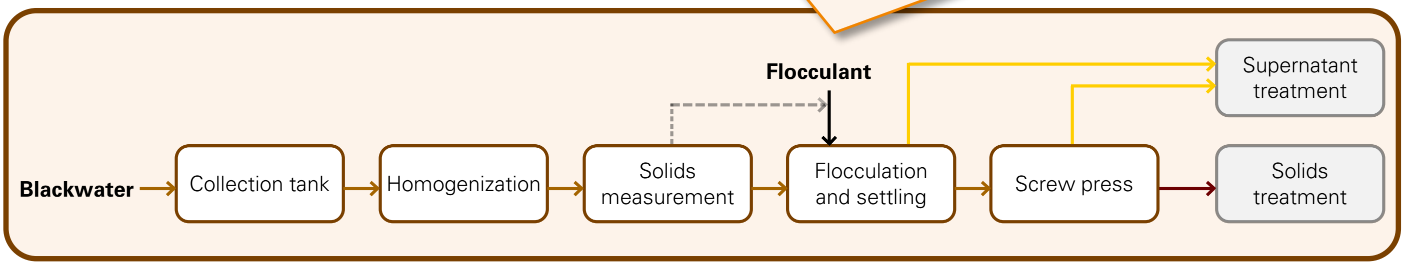

Figure 1: Process flow of the wastewater dewatering unit
(The grey boxes are not yet part of the system, but are part of the complete treatment process.)

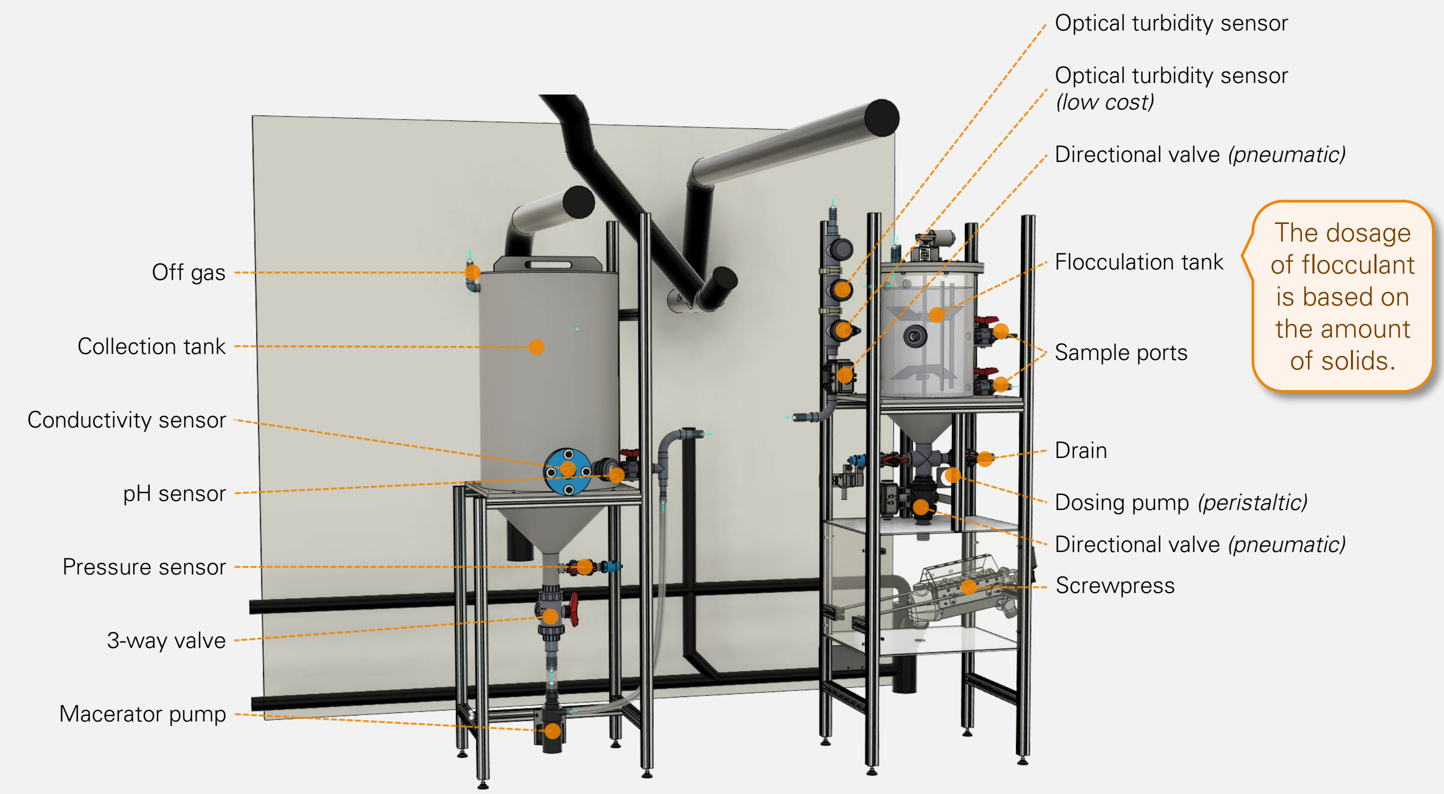

Figure 2: 3D schematic of the components of the wastewater dewatering unit

Key features and performance metrics

- Custom-built screw press with a 3D-printed screw that dewaters solids up to 25% (total solids) and removes more than 60% of the total suspended solids.
- Low-cost (Amphenol TSW-10) and high-cost (Endress+Hauser CUS50D) light-attenuation sensors predict the total suspended solids with R^2=0.9, up to 4 g/L with TSW-10 and up to 40 g/L with CUS50D.
- With a flush water demand of 60 L per capita per day, the required flocculant dosage of 1.5 kg per capita per year results in a cost of 7 USD per year.
- Performance metrics for four consecutive batches during normal office hours are summarized in **Table 1**.

Table 1: Performance metrics of the dewatering unit

Metric (average values)	Value	Unit
Batch volume	41.2	L
Process time	810	s
Capacity	183	L/h
Specific energy demand	0.4	kWh/m^3
Specific space requirements	16	m^2/(m^3/h)
Inflow COD	3.1	g/L
Inflow TSS	1.8	g/L
Supernatant COD	0.8	g/L
Supernatant TSS	0.5	g/L
Screw press effluent COD	1.4	g/L
Screw press effluent TSS	0.7	g/L
Separation efficiency TSS	63	%
Reduction in COD	55	%
Solids output TS	17	%
Flocculant (emulsion) demand	70	mg/L

COD: Chemical oxygen demand
TSS: Total suspended solids
TS: Total solids

Design approach

The design goals were modularity and manufacturability using prototyping methods, such as 3D-printing and laser-cutting of sheet metal (See **Figure 3**). This enables rapid adaptation in different contexts. Because the screw is completely 3D-printed, multiple shapes of screws were tested within a short period of time (See **Box 1**). Additionally, we adhered to the principles of Design for Manufacturing and Assembly (DFMA) to facilitate the manufacturing and replicability of the unit. Complex components can be mass produced and replacement parts easily available. In contrast to dewatering technologies in large wastewater treatment plants, no heavy machinery is needed for the installation and/or maintenance of the system. This is important because it makes it more likely that these small-scale wastewater treatment systems are built and installed in dense urban areas.

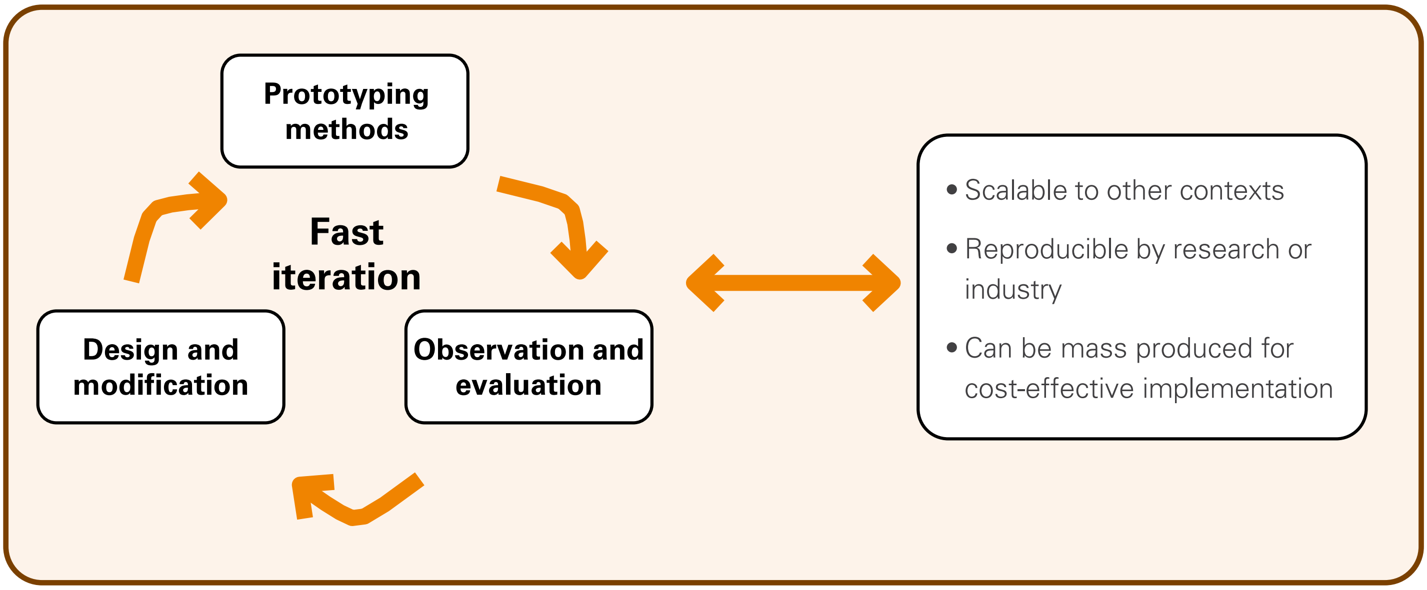

Figure 3: Illustration of the design principles used to design the wastewater dewatering unit.

Box 1: Determining the shape of the screw in the screw press with 3D-printing

Prototype A:

- **Shape**: Short thickening zone (region with small diameter of inner shaft) for equal distribution of the liquid removed over the entire press length.
- **Observation**: High friction between the cake and cage due to the sharp transition from thickening to dewatering.
- **Modification**: Increase thickening zone, to first let the liquid drain without actively pressing.

Prototype B:

- **Shape**: Long thickening zone to allow for liquid removal with reduced friction between the cake and cage.
- **Observation**: High torque required for dewatering due to the short dewatering zone.
- **Modification**: Balanced thickening and dewatering over the entire screw length.

Prototype C:

- **Shape**: Constant increase of the inner shaft diameter over the press.
- **Observation**: Medium torque required for dewatering, and reduced friction between the cake and cage compared to prototype A.

Overall gains:
- Easy adaptation depending on use through minor design changes.
- Design suited for mass production (e.g. injection molding, metal milling).
- Scaling and modification for other applications are possible.

Opportunities

Water reclamation

In the NEST building, each toilet flush uses up to 7 liters of water. This water has the potential to be reused if adequately treated. Use of the screw press caused a high removal (55%) of the total chemical oxygen demand, greatly reducing the oxygen demand for further biological treatment. Water from blackwater can alleviate water stress; however, the selection of water reuse options needs to follow a risk-based approach to protect public and environmental health.

Resource recovery from solids

There are multiple treatment processes that enable resource recovery from solids in the blackwater. Although composting enables recovery of organic matter, and is a beneficial soil amendment, it requires mixing the solids with a bulking agent (e.g. food waste or wood chips) and proper process control to maintain the high temperatures necessary for effective pathogen reduction. In this case, the use of polyacrylamide-based flocculants is not recommended, due to their low biodegradability and uncertain fate in the environment. Energy can be recovered via the combustion of the solids, with or without prior carbonization (pyrolysis). This option requires further drying of the solids fraction following dewatering of the blackwater and a stable long-term operation to maximize resource recovery [2]. Consistent dewatering of blackwater is an important step towards resource recovery from the solids. In addition, combustion reduces the need for pathogen reduction during drying, as human contact is reduced and the pathogens are eliminated during pyrolysis and the combustion.

Bio-based flocculants

We are currently investigating the use of bio-based flocculants for dewatering. This would alleviate the disadvantages associated with commonly used polyacrylamide-based flocculants, such as low biodegradability and potential carcinogenicity. Bio-based flocculants, i.e. chitosan from shrimp shells or modified starch from agricultural waste, are more biodegradable and, thus, have less negative impacts on the end use of the resource recovery products. Both polyacrylamide- and bio-based flocculants are effective for separation by settling [3]. However, flocs formed with chitosan or modified starch are smaller and weaker than those made with polyacrylamide-based flocculants and, therefore, break apart more easily in a screw press, which leads to a lower total suspended solids (TSS) removal. To have a treatment comparable to that with polyacrylamide, either the floc strength needs to be increased or a dewatering technology has to be used that reduces the shear force.

Application

The unit's modularity makes it readily adaptable for different applications that require a low-footprint, including building-scale blackwater treatment plants, boats, trains or public toilets. It also opens up the possibility for more decentralized treatment, reducing the energy and costs required to transport wastewater to treatment (pipe-, or road-based). Furthermore, its modularity makes it easy to modify and optimize as needed. For example, flocculant demand increases when working with wastewater that has a high content of dissolved organics. Degrading dissolved organics by promoting controlled aerobic or anaerobic stabilization processes prior to dewatering can reduce the flocculant demand and increase solids removal, lowering the requirements for a subsequent effluent step and overall treatment costs, and allow for the unit to have a smaller footprint. Knowledge gained from the use of this system can be transferred to the treatment of wastewater that is stored onsite prior to treatment (aka fecal sludge). The sensors installed in this system can be used in the treatment of stored wastewater, although the greater variability of the stored wastewater characteristics may lead to reduced sensor accuracy [4]. In addition, stored wastewater might already have undergone degradation processes during storage, which can break down water-holding compounds and dissolved organics [5], reducing the flocculant demand and increasing the dewatering performance.

References

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About the Water Hub in NEST

The NEST (Next Evolution in Sustainable Building Technologies) is a modular research and innovation building established by the Swiss research institutions Empa and Eawag. Located on the Empa campus in Dübendorf and inaugurated in 2016, NEST provides real-world conditions for testing and demonstrating sustainable technologies in construction, energy, and water. Its modular design features a central backbone and plug-and-play units that are developed, tested, and replaced by interdisciplinary teams from academia, industry, and the public sector.

NEST bridges the gap between lab research and market application, accelerating the development of scalable, innovative solutions.

The Water Hub is located in the basement of NEST and operated by Eawag researchers. Using a non-sewered approach, wastewater streams are separated and treated directly on-site, improving treatment efficiency and enabling resource recovery. This is especially useful in places where centralized infrastructure cannot be built or is at capacity limit, such as in rapidly growing urban areas.

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