Low-cost Struvite Reactor

Operation Manual

Eawag – Swiss Federal Institute of Aquatic Science and Technology

UN-HABITAT – United Nations Human Settlement Programme

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The present document is a beta-version. Your valuable feedback will be much appreciated.
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Summary

If urine is collected separately from other wastewater streams, it can be reused as a fertilizer and valuable nutrients can be extracted. To collect human urine – and the nutrients contained in it – directly where it is produced, helps to close the nutrient cycle.

Because of the high water content in urine, the nutrient concentration is low compared to solid fertilizer. Transportation and storage of large urine volumes is not convenient. Therefore, the present research project aimed at reducing the volume and transfer urine into a solid fertilizer by recovering the nutrients (mainly phosphorus) into a phosphate mineral called struvite ($MgNH_4PO_4 \cdot 6H_2O$).

The described set-up in this manual addresses a low-cost solution for struvite production for processing the urine produced by up to 1600 citizen (1600 l urine$\cdot d^{-1}$ can be processed during 8 h by running the struvite reactor 8 times, while 1 person produces at minimum 1 l urine per day [Rauch et. al, 2002]). This set-up cannot be considered as economically viable, since the struvite produced cannot cover the costs for its production. The system can be more efficient at a larger scale and can help to offset the costs of wastewater treatment.

Acronyms

Eawag	Swiss Federal Institute of Aquatic Science and Technology
MAP	Magnesium ammonium phosphate (also called 'struvite')
P	Phosphorus
PP	Polypropylene (plastic piping material)
PVC	Polyvinyl chloride
STUN	Struvite recovery from urine in Nepal
Sandec	Department for Water and Sanitation in Developing Countries at Eawag
UN-Habitat	The United Nations Human Settlement Programme

Units & Symbols

In general, the metric system and ISO units are used throughout this report.

This manual covers all instructions needed to operate the system for struvite production as installed at the Kuleshwor Secondary School in Kathmandu, Nepal. This system was designed and operated during the STUN research project. This particular set-up will be explained in detail, but it can also be used as a main guide for differently adapted systems in other places and environments. For the description of the effluent treatment (Figure 1) system with a rotating biological contactor (RBC) refer to the separate manual: *www.eawag.ch/stun*

1 Production process

Struvite harvesting key features and overview

1.1 General description

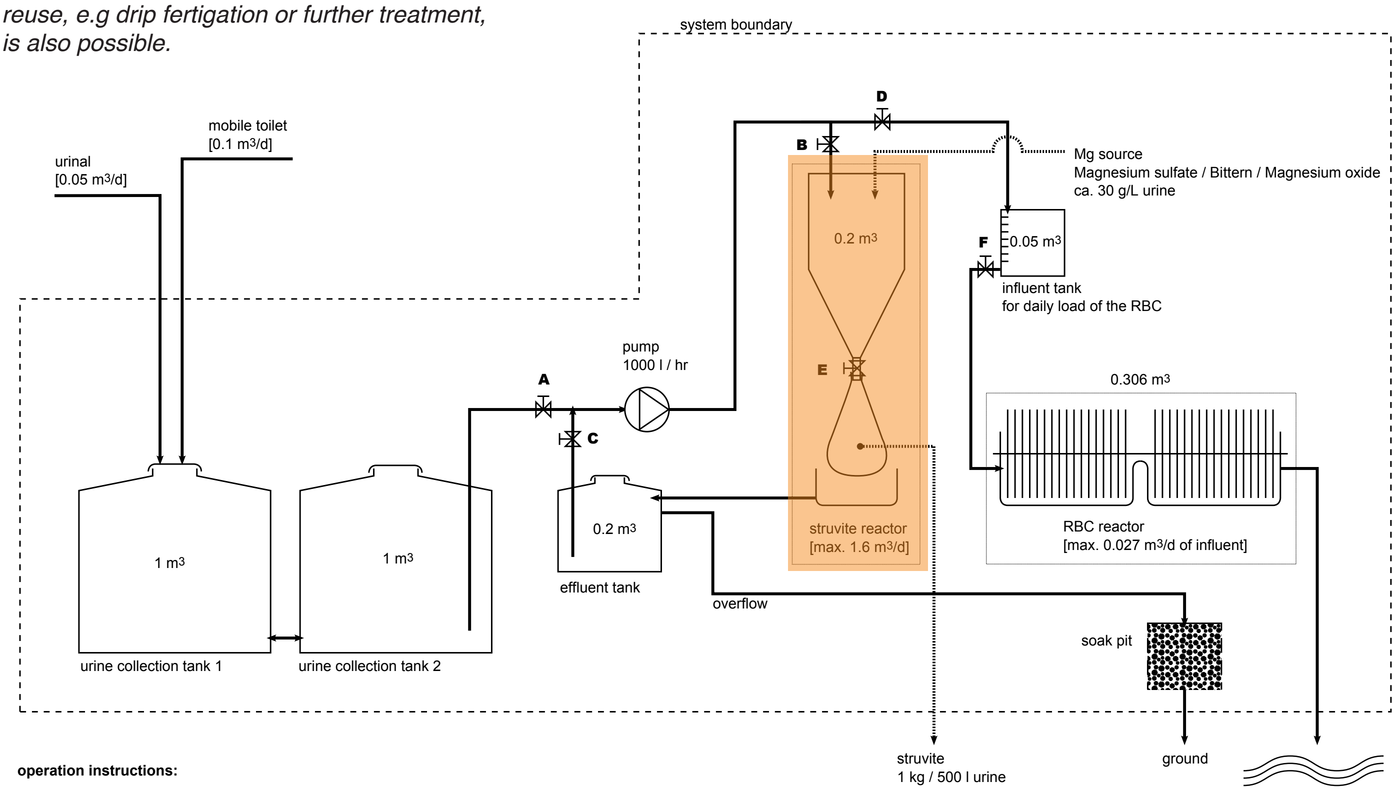
The system is designed to produce struvite on a regular basis. If sufficient urine is available, approximately 1600 litres urine can be processed and 3 kg of struvite can be produced daily.

However, the effluent treatment can show some limitation. Only up to approximately 35 litres effluent can be treated by the rotating biological contactor (RBC), the rest is disposed into a soak pit. Since the soil is high in clay and disposed material, the infiltration rate of the soak pit is very low.

The system consists of urine collection, a struvite reactor for struvite precipitation and a pilot scale RBC reactor to treat a small fraction of the effluent from struvite production before disposing it to the environment.

Figure 1: *The rotating biological contactor (foreground left) and the struvite precipitation reactor (background right).*

Figure 2: *Schematic diagram of the struvite production process comprising the struvite precipitation reactor (shaded area) and the effluent treatment system with a rotating biological contactor (RBC). Alternative effluent reuse, e.g drip fertigation or further treatment, is also possible.*



1.2 System overview

This chapter gives an overview and a brief description of the different components (Figure 2) of the struvite production system. The dimensioning of different parts of the set-up are determined by the size of the struvite reactor. The volume of 200 L for the struvite reactor was chosen according to the assumption that this reflects the upper limit of a reactor that can be built at low costs and be operated manually. Assuming that the operation of the struvite reactor for one batch takes around one hour, 1600 L urine can be processed during a 8 hour working day. The urine collection tanks with a capacity of 2000 L where designed to store sufficient urine for one full day operation.

1.2.1 Valves

A empty urine tanks

B fill struvite reactor

C empty effluent tank

D fill RBC influent tank

E empty struvite reactor

F controls inflow rate into RBC reactor

1.2.2 System components

1 Urine storage tanks: 2000 L urine can be stored in two connected 1 m^3 polyethylene tanks. The urine from the school is directly conveyed through a pipe into the storage tanks. Urine can also be delivered from another source (i.e. mobile toilets).

2 Struvite reactor: In the struvite reactor, magnesium is added to urine to precipitate struvite. The powder is separated from the liquid through a filter bag.

3 RBC (rotating biological contactor): Decreases the high nitrogen concentration in the effluent from the struvite reactor to minimize the environmental impact.

4 Effluent tank (of the struvite reactor): Collects the liquid effluent issued from the struvite production process.

5 Influent tank (for the RBC reactor): Provides a controlled and constant inflow rate to the RBC.

6 Soak pit: Prevents the effluent tank from overflowing.

7 Pump: Provides three different functions:
a) pumping stored urine into struvite reactor.
b) pumping effluent from the struvite reactor into the RBC.
c) pumping effluent from the struvite reactor to the soak pit.

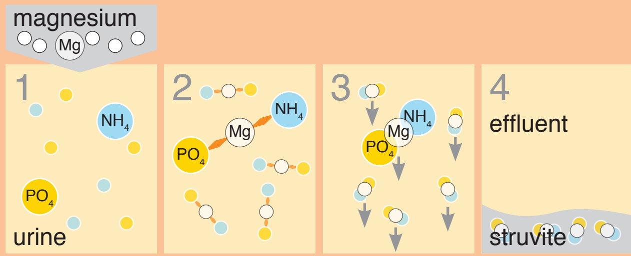
1.3 Struvite reactor

A detailed a description on how to build a low-cost struvite precipitation reactor, as used in the STUN project in Nepal, can be found in the construction manual: *www.eawag.ch/stun*

An overview of the struvite reactor components is presented in Figure 3. For a brief description of struvite precipitation chemistry and the mechanisms involved in struvite production refer to the box to the right. Figure 4 presents an overview of the struvite recovery process using the low-cost struvite precipitation reactor as described in this manual.

How is struvite formed?

Urine contains phosphate (PO_4) and ammonium (NH_4); both are important nutrients. If magnesium (Mg) is added to urine, these substances will bind and form struvite ($MgNH_4PO_4 \cdot 6H_2O$) powder, which can be filtered out.



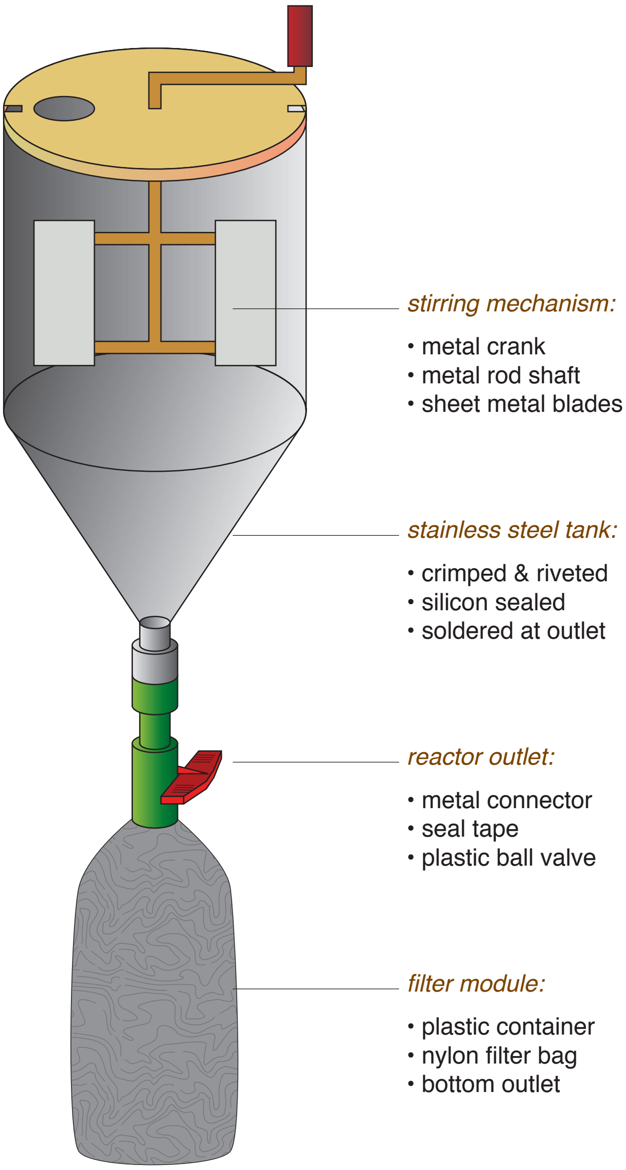


Figure 3: *The struvite precipitation reactor with a nylon filter bag used by the STUN project.*

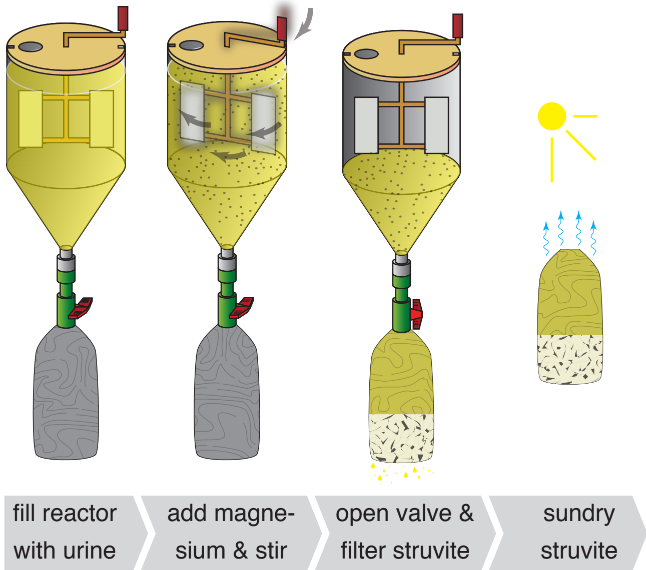


Figure 4: *Overview on the struvite production process using a low-cost struvite precipitation reactor.*

2 Reactor operation

Step-by-step description of struvite production

This section describes in detail how the struvite reactor has to be operated and maintained in order to produce struvite.

2.1 Urine collection

The two urine storage tanks contain sufficient urine for a full day of continuous operation of the struvite reactor (Figure 5). For continuous operation, urine has to be delivered daily from an outside source, since the urine quantity produced at the school is negligible.

The urinals at the school (Figure 6) are directly connected to the urine storage tanks. On average, 12.5 liter of urine per school day is produced. To optain access to the urine storage tanks, the bricks on the corrugated iron sheets has to be removed Figure 7), before the sheets themselves can be removed (Figure 8). Urine can be filled directly into the tanks from the top from various sources e.g. tank vehicles.

Through sedimentation of solids from the urine, some sludge will accumulate over time at the bottom of the storage tanks. This sludge contains valuable nutrients and has to be removed regularly, in order to ensure maximum nutrient recovery. A filter at the end of the outflow pipe prevents the pump from clogging (see inset Figure 8). This filter has to be checked in regular intervals and cleaned if necessary.

Figure 5: *The struvite reactor with a nylon filter bag to separate the precipitated struvite powder from the liquid.*

2.2 Magnesium sources

Sufficient urine and a suitable magnesium source have to be available for the process. If magnesium (rather magnesium cations Mg^{2+}) is added to urine, struvite will be formed together with the phosphate and ammonium contained in the urine.

Fine magnesium oxide powder obtained from calcined magnesite rock, magnesium sulfate or bittern are suitable for the struvite precipitation process. The required amount depends on the quality of the precipitant and the phosphate concentration in the urine. The different magnesium sources used in Nepal are described below. Table 1 specifies the dosage, based on an average phosphate concentration of 200 mg P·L^{-1} urine.

- *Magnesite rock:* As magnesite rock is not soluble in water or aqueous solutions, ground magnesite rock has to be calcined (i.e. heat-treated at approximately 500°C for 2 hours) to obtain soluble magnesium oxide suitable for the struvite production process. Typically, magnesium rock contains about 27 % magnesium.
- *Bittern:* After sodium chloride extraction from seawater through precipitation, the remaining salt brine contains high magnesium and chloride concentrations (appr. 27 g Mg·L^{-1}). Further evaporation of the remaining liquid can increase the concentration to up to 10 % of mass (i.e. 100 g Mg per 1 kg salt brine).
- *Magnesium sulphate:* A widely available fertilizer product, magnesium sulphate granules can be used as precipitant in the struvite production process. However, input costs are higher than for other magnesium sources. Pure magnesium sulphate heptahydrate ($MgSO_4 \cdot 7H_2O$) contains 9.9 % magnesium.

Table 1: *Dose of different magnesium sources required for struvite precipitation (based on measured average phosphate concentration in Nepal).*

magnesium source	magnesium oxide	bittern (salt brine)	magnesium sulfate
formula	MgO	Mg^{2+}	$MgSO_4 \cdot 7H_2O$
specifications	D < 53 μm	27.5 g Mg·L^{-1}	
Mg:P ratio	1.5	1	4.41
Dose:			
for 1 L urine	0.8 g	50 mL	3 g
for 200 L urine	160 g	1 L	600 g

Figure 6: *The toilet building at the Kuleshwor Secondary School in Kathmandu. Urine is collected in tanks (see below).*

Figure 7: *The collected urine is conveyed to two underground tanks. The soak pit in the back absorbs overflowing urine.*

Figure 8: *Urine flows into the two underground PP tanks through a 100 mm PVC pipe (A) and is pumped out through a 32 mm PP-R pipe (B) with a screened inlet (see inset right).*

2.3 Struvite precipitation

Step	Description	Details
1	Empty reactor	• Open valve E.
2	Fill reactor	• Make sure valve C, D and E are closed and valve A and B remain open (see Figure 2). • Put the pipe into the reactor. • Activate the pump and pump 200 liter of stored urine into the struvite reactor (fill level approx. 10 cm below the top). • Switch off the pump and remove the pipe from the struvite reactor.
3	Add magnesium	• Open the lid of the struvite reactor • Add the needed amount of magnesium (see Table 1 above for quantity). If magnesium oxide or magnesium sulfate is used, it should be first dissolved in a small bucket filled with urine. • Close the lid of the struvite reactor.
4	Struvite precipitation	• Use the handle on top to stir about 10 min. Start immediately after magnesium addition to avoid its sedimentation. 
5	Attach filter bag	• Attach the filter bag as shown in the Figure to the right. Wrap the string around the pipe and fix it tightly. 
6	Empty the reactor	• Open valve E slightly to let the effluent flow into the filter bag . Do not open the valve fully to keep the outflow rate at an acceptable rate. • Wait until the struvite reactor is fully emptied. 
7	Harvest struvite	• If the filter bag is fully drained, close valve E and detach the filter bag. • Hang up the bag for drying. • After the bag is completely dry, the struvite powder can easily be removed. • Clean the filter bag, which will be reused for the next batch. • Note: Several bags must be available to ensure a continuous work flow.

2.4 Effluent treatment

The effluent from the struvite production still contains a high concentration of nitrogen, which cannot be disposed to the environment without causing negative effects to it. The effluent could either be used as a fertilizer through irrigation or further processed into a less harmful solution. The main objective in treating the struvite effluent is to reduce the high nitrogen concentration, which is mainly present in form of ammonium. To lower the ammonium concentration, a small scale rotating biological contactor (RBC) was built. Because the RBC is dimensioned to treat up to 27 L urine per day at a ammonium concentration of 7000 mg·L^{-1} some of the struvite effluent has to be disposed in an already existing soak pit. For details on the RBC construction and operation refer to the further readings. The effluent from the struvite production is collected in the 200 litre effluent tank. Before the struvite reactor can be operated, the effluent tank has to be fully emptied first. This can be done either by pumping some of the effluent to the RBC inflow tank and/or by pumping the effluent into the soak pit (Figure 10).

2.4.1 Procedure to empty the effluent tank

Close valves A and B and open valves C and D. Put the end of the hose, which is attached to the valve D (Figure 9), into the soak pit (Figure 10). Activate pump for sufficient time for the effluent tank to empty.

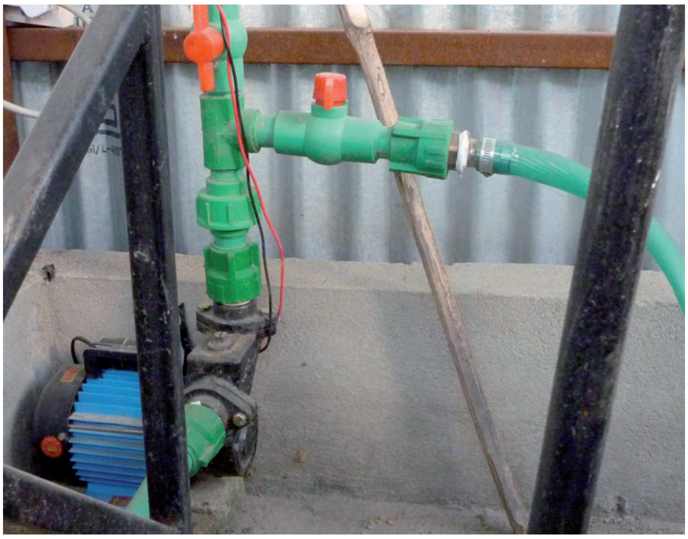


Figure 9: *Pump used to pump urine into the struvite reactor and effluent to the collection tank.*

Figure 10: *The soak pit absorbs overflowing effluent from the collection tank.*

Further readings

More information on the project and manuals on reactor construction and operation please look at:
www.eawag.ch/stun

You may find following documents on the website:

- Low-cost Rotating Biological Contactor: Operation and Maintenance Manual
- Low-cost Rotating Biological Contactor: Construction Manual
- Low-cost Struvite Recovery: Construction Manual

Other reports about the STUN project, on the production and economy of struvite, the re-use of effluent and the construction of a struvite reactor.

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