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UN-Habitat Nepal



**Process optimization of low-cost  
struvite recovery**

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June 2009 – Asār 2066

Process optimization of low-cost struvite recovery

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STUN is a joint collaboration project of Eawag (Swiss Federal Institute of Aquatic Science and Technology) and UN-Habitat Nepal (The United Nations Human Settlement Programme), Water for Asian Cities Programme. The present report is submitted to EPFL (Swiss Federal Institute of Technology Lausanne) for the degree in MSc in Environmental Sciences and Engineering.

MSc thesis

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# Abstract

## Keywords:

*ecological sanitation*

*nutrient recycling*

*struvite precipitation*

Struvite ( $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$ ) recovery from wastewater streams has been known as an efficient nutrient recycling method. However, current research has predominantly addressed high-end solutions to overcome fertilizer shortages in agriculture and prevent eutrophication in receiving waters.

The present study focused on low-cost struvite recovery from stored human urine, by optimizing a process developed at pilot scale in the peri-urban settlement of Siddhipur in the Kathmandu Valley (Nepal). A combination of laboratory and field experiments were conducted to develop a design for an improved cost-effective struvite production reactor – completely constructed with locally available materials.

With emphasis on process technology, the following conclusions can be drawn for low-cost struvite recovery:

- Liquid-solid separation reaches high efficiency (90 %) by filtration through widely available filter materials, such as nylon or cotton fabrics, constructed as filter bags.
- Additional flocculation is not required nor adequate for the struvite recovery process. Tested flocculants (alum, lime, PAM, moringa oleifera) showed no significant effect on recovery efficiency.
- The reactor design, featuring a cylindrical galvanized steel tank with tapered bottom and central outlet, proved to be easily operable and low in maintenance requirements.
- As a precipitant, brine containing high magnesium concentrations can be obtained from salt manufacturing in India. Still, the shipment of larger quantities needs to be resolved.
- Local magnesite deposits are not extracted and cannot be processed at present. However, high-grade MgO ore deposits have been known in the region, and processed MgO might be available in the future.
- Granulation of the produced struvite powder is realizable with low-cost equipment, in order to manufacture an user-friendly, granulated fertilizer product.

For struvite recovery to be economically viable at a small business scale, considering present fertilizer market prices, environmental and socio-economic values need to be included in the overall balance; reduction of eutrophication through sewage discharge in surface waters, independence from fertilizer imports, or incentives for improved sanitation accompany the simple nutrient recycling process.

## Résumé

### Mots clés:

*assainissement écologique*  
*précipitation de struvite*  
*recyclage de nutriments*

La récupération de struvite ( $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$ ) à partir d'eaux usées est connue en tant que méthode de recyclage de nutriments efficace. Néanmoins, la recherche actuelle se concentre principalement sur des solutions de haute gamme, afin de surmonter les pénuries d'engrais en agriculture ou de réduire l'eutrophisation de cours d'eaux récepteurs.

À travers l'optimisation d'un procédé développé à échelle pilote dans le village périurbain de Siddhipur dans la Vallée de Kathmandou (Népal), la présente étude vise à une récupération de struvite à bas coûts à partir d'urine humaine. La combinaison d'expérience de terrain et en laboratoire a conduit à la conception d'un réacteur – construit entièrement avec des matériaux locaux – de production de struvite amélioré .

Dans une perspective de génie de procédés, les conclusions suivantes sont valables pour la récupération de struvite à bas coûts:

- La séparation liquide-solide atteint une efficacité élevée (90 %) moyennant de la filtration à travers de matériaux facilement accessibles (p. ex. nylon ou coton), confectionnés en forme de sac filtrant.
- L'addition de flocculants n'est pas requise pour le processus de récupération de struvite. Les flocculants testés (alun, chaux, PAM et moringa oleifera) n'ont pas montré d'impact significatif sur l'efficacité de récupération.
- Le réacteur cylindrique en acier galvanisé, avec fond conique et sortie centrale, est facilement utilisable et de faible entretien.
- Le précipitant, une saumure à haute concentration de magnésium peut être obtenu de l'industrie saline indienne. Des formalités de transport restent à régler.
- Des gisements de magnésite locaux ne sont pas exploités et ne peuvent pas être traités pour le moment. Du minerai à haute teneur en MgO pourrait ainsi être aisément disponible dans un futur proche.
- Afin de produire un engrais adapté aux besoins des utilisateurs, la granulation de la poudre de struvite et réalisable à bas coûts.

Pour que la récupération soit économiquement viable à l'échelle d'une petite entreprise (sous considération des prix courant d'engrais), les dimensions environnementales et socio-économiques doivent être prises en compte lors du bilan complet; une réduction de l'eutrophisation causée par les eaux usées, l'indépendance des importations d'engrais ou l'incitation à un assainissement amélioré sont des conditions sine qua non au processus de récupération des nutriments.

# Acronyms

AIC	Agriculture Input Company (an enterprise of the Government of Nepal), Kathmandu, Nepal
AEC	Aquatic Ecology Centre at Kathmandu University, Dhulikhel (Kavrepalanchok), Nepal
BS	Bikram Sambat: Calendar used in Nepal; 56.7 years ahead of the Gregorian Calendar's AD
CIUD	Centre for Integrated Urban Development (NGO), Kathmandu, Nepal
DAP	di-ammonium phosphate $(\text{NH}_4)_2\text{HPO}_4$
Eawag	Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland
EcoSan	ecological sanitation
ENAC	School of Architecture, Civil and Environmental Engineering, EPFL, Lausanne, Switzerland
ENG	Department for Process Engineering, Eawag, Dübendorf, Switzerland
ENPHO	Environmental and Public Health Organization (NGO), Kathmandu, Nepal
EPFL	Swiss Federal Institute of Technology Lausanne
FAO	Food and Agriculture Organization of the United Nations
HAP	hydroxyapatite
IC	ion chromatography
ICIMOD	International Centre for Integrated Mountain Research (NGO), Kathmandu, Nepal
ICP-OES	inductively coupled plasma – optical emission spectroscopy
IDE	International Development Enterprises (NGO), USA
IFFCO	Indian Farmers Fertilisers Cooperative Limited
IIT	Indian Institute of Technology
INR	Indian Rupees
KMC	Kathmandu Metropolitan City (municipal administration of Kathmandu)
KU	Kathmandu University, Dhulikhel (Kavrepalanchok), Nepal
LCE	Laboratoire de chimie environnementale (Environmental Chemistry Laboratory, EPFL)
MoAC	Ministry of Agriculture and Cooperatives (Government of Nepal)
MOP	Myriad of potash
MSc	Master of Science
NARC	National Agricultural Research Council (research institute affiliated to the MoAC), Kathmandu, Nepal
NTU	nephelometric turbidity unit
NRs	Nepalese rupees (present exchange rate: 1 € $\approx$ 100 NRs)
PAM	polyacrilamide
PE	polyethylene
PP	polypropylene
RO	reverse osmosis
rpm	revolutions per minute
Sandec	Department for Water and Sanitation in Developing Countries, Eawag, Dübendorf, Switzerland
SDC	Swiss Agency for Development and Cooperation (part of the Swiss Federal Department of Foreign Affairs)
SGN	size guide number (used in fertilizer industry): median particle diameter $d_{0.5}$ in mm multiplied by 100
SIE	Sciences et ingénierie de l'environnement (Environmental Sciences and Engineering Programme), EPFL
SS	suspended solids
STUN	Struvite recovery from urine at community scale in Nepal (project of Eawag)
TS	total solids
UC	user committee
UD	urine diversion
UDDT	urine diverting dry toilets
UN-Habitat	The United Nations Human Settlement Programme
USDA	United States Department of Agriculture
VDC	village development committee
WAC	Water for Asian Cities (programme of UN-Habitat)

# Units

°Bé	Degree Baumé expressing salinity of seawater as density $\rho = 145 / (145 - \text{°Bé})$ at 20 °C
ānā	Area unit used in Nepal. 1 ānā $\approx$ 30 m <sup>2</sup>
BS	Bikram Sambat: Calendar used in Nepal; 56.7 years ahead of the Gregorian Calendar's AD
karoḍ	1 karoḍ = 10'000'000 (also spelt 'crore')
lākh	1 lākh = 100'000
ropani	Area unit used in Nepal. 1 Ropani = 16 ānā $\approx$ 500 m <sup>2</sup>
rupee	Present exchange rate: 1 € $\approx$ 100 NRs

# 1 Introduction

## *Field work for fertilizer production from urine*

Closing the link between sanitation and agriculture – between human outputs and inputs – has been considered in numerous concepts, though practical applications – apart from direct application of urine – have not been implemented at a broader scale yet. The STUN (Struvite recovery from urine in Nepal) project's struvite reactor experienced an overwhelming interest in Nepal. With an approach to adapt one possible option of nutrient recycling, a first pilot scale reactor had been developed and tested in the village of Siddhipur, in the Kathmandu Valley.

Notwithstanding that the operation of the first version of the "fertilizer making machine" proved to be a success, the process itself left room for improvement. To develop a sturdy, user-friendly, and affordable procedure, the process had to be optimized. The lessons learnt from the first project phase (August 2008 to January 2009) lead to the conception of a second reactor and to further insight concerning process inputs, outputs and surroundings.

As key factors for an efficient struvite recovery from urine, two aspects were identified:

- Liquid-solid separation (separating the precipitated struvite from the effluent).
- Magnesium source origin and processing (besides urine, magnesium is the main process input).

For the process to be ready for dissemination, these parameters had to be fine-tuned. By doing this in-depth study on process optimization, the STUN project team hoped to bring struvite recovery one step further and contribute to improved sanitation, easier access to fertilizer, and reduced environmental pollution.

The interest in struvite recovery, which the project had experienced from the beginning, was certainly one of the main motivating factors to continue the research. Expectations of a promising new technology were high, but at the same time, it was the support from many sides that has made this project possible.

# 2 Background

*Struvite harvesting key  
features and STUN's  
starting points*

## 2.1 Project motivation

Struvite precipitation as nutrient recycling technology has been extensively studied over the last decade. A simple precipitation reaction, which allows recovering the phosphorus contained in urine in powder form, has been developed into numerous high-end processes, though few have reached industrial applications yet. The majority of research projects around the world continue to focus on energy intensive technologies, which are beyond reach for developing countries.

Nutrient recycling from wastewater streams comprises the dual advantage of producing crucial input substances for agricultural needs and improving the sanitary situation (entailing many benefits, such as improved public health, prevention of eutrophication in receiving waters through untreated sewage, etc.). Considering the simplicity of the struvite precipitation reaction, the STUN project hypothesized that a sturdy low-cost approach could be developed, thereby increasing accessibility to sanitation solutions and fertilizer production. By creating the link between waste treatment and agricultural inputs, a value-added product would be generated.

Therefore, the STUN project aimed to adopt the principles of struvite precipitation into a robust, locally available technology, which could be easily reproduced and operated at a local scale. Struvite recovery is not an integrated approach to sanitary issues, it is moreover a module (Figure 1), which will complement other treatment methods (e.g. biogas production through anaerobic digestion from organic waste material). The struvite precipitation process is technically suitable for applications ranging from the household scale to the industrial scale, although from an economic point of view, the operation requires a larger scale to be viable.

## 2.2 Project framework

The one-year STUN (Struvite recovery from urine at community-scale in Nepal) project, initiated by Eawag in collaboration with UN-Habitat Nepal, explored the potential of a cost-efficient nutrient recycling technology, following the steps outlined below (Figure 2).

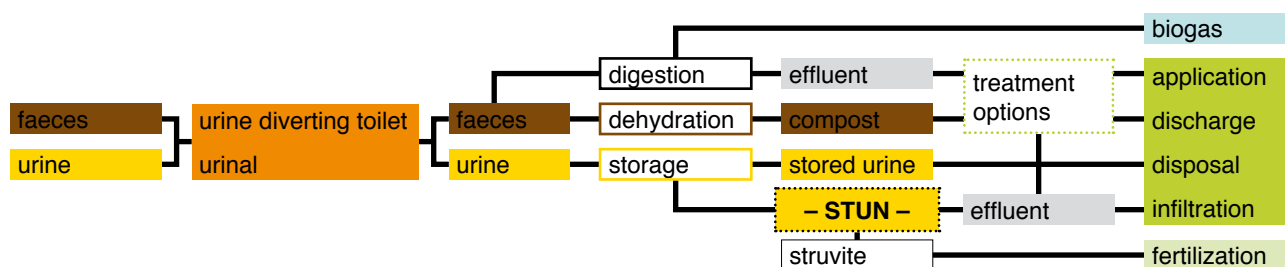
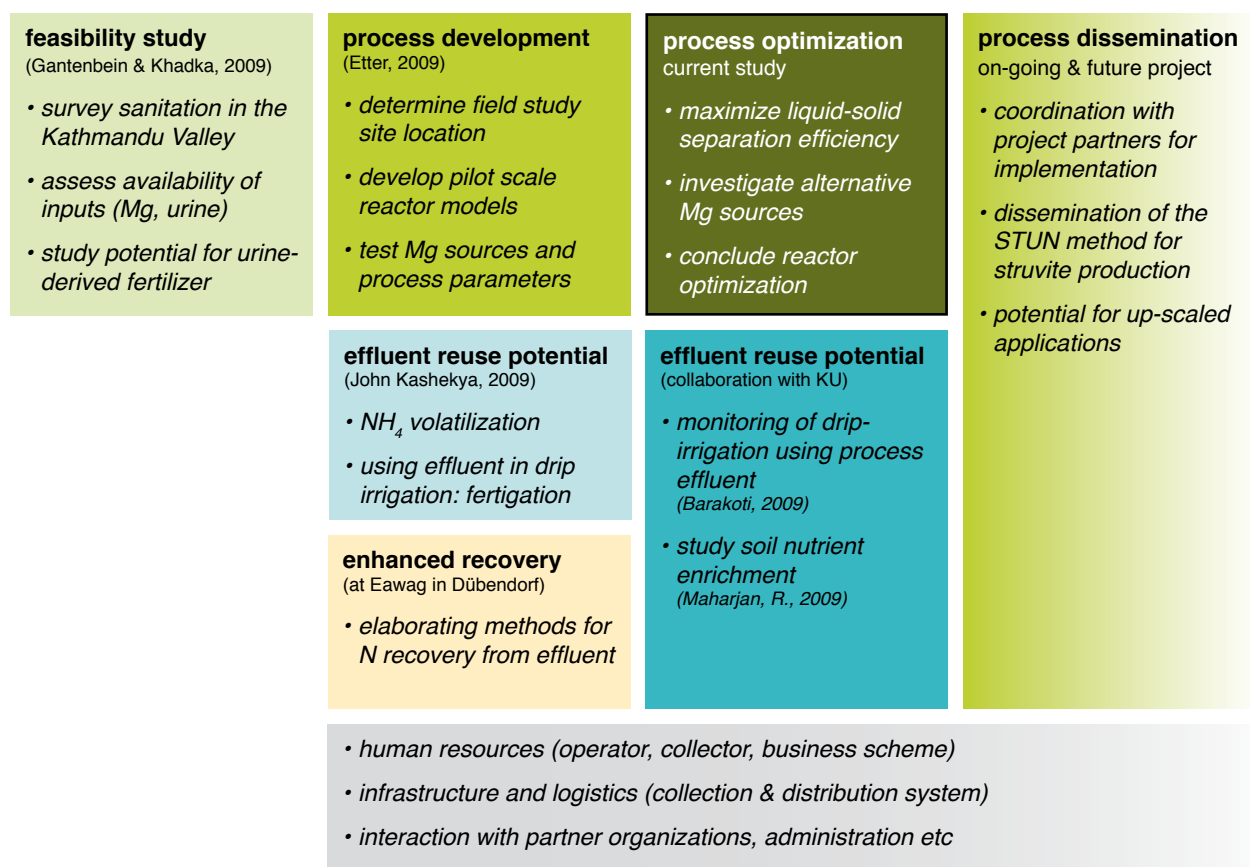


Figure 1: Struvite recovery is one possible option in a range of sanitation approaches (concept from Tilley et al., 2008b).



2008 – May – Jun – Jul – Aug – Sep – Oct – Nov – Dec – 2009 – Jan – Feb – Mar – Apr – May – Jun –

Figure 2: Project framework of the STUN (Struvite recovery from urine at community-scale in Nepal) project.

For its applied research, the STUN project has benefited from the interaction with various institutions:

- **UN-Habitat**: the main local partner, supporter and facilitator of office infrastructure and many valuable contacts. Collaboration within the UN Water for Asian Cities Programme (WAC).
- **Kathmandu University KU**: collaboration for lab work and coordination of two BSc thesis students.
- **Siddhipur Drinking Water and Sanitation User Committee**: the local administration coordinating sanitation projects at the field study site.
- **Indian Institute of Technology IIT, Delhi**: coordination of research on urine harvesting and reuse.

Furthermore, the following organizations have provided valuable advice to the research work:

- **SSMP**: Sustainable Soil Management Programme (a Helvetas project), Kathmandu, Nepal
- **ICIMOD**: International Centre for Integrated Mountain Development (international NGO), Kathmandu
- **IDE**: International Development Enterprises Nepal (NGO with headquarters in the USA)
- **NARC**: National Agriculture Research Council (research institute affiliated to the Ministry of Agriculture and Cooperatives of the Government of Nepal)
- **ENPHO**: Environmental and Public Health Organization (NGO), Kathmandu, Nepal

## 2.3 The STUN project – previous research

### 2.3.1 Preliminary feasibility study

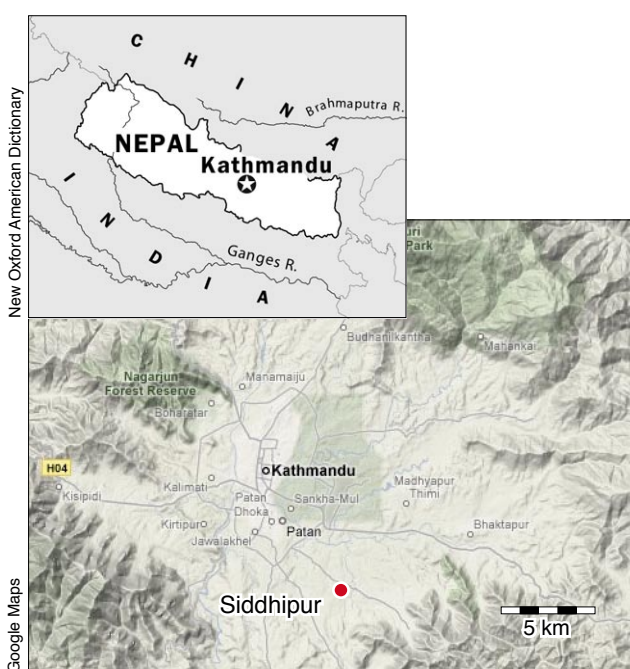
The STUN project's first phase, a feasibility study (Gantenbein & Khadka, 2009), confirmed that there is a potential for struvite production in Nepal, taking into account the following reasons (amongst others):

- Urine can be collected without additional infrastructure from the existing EcoSan toilets (urine diverting dry toilets promoted throughout Nepal).
- Currently, only 50 % of the urine is used as a fertilizer by direct application.
- Magnesium, as a process input, can be imported into Nepal, although it is not easily available on the local market.
- As most farmers resort to urea for fertilization, struvite would be an ideal supplement considering its high phosphorus content.
- Social acceptance of a urine-derived fertilizer, such as struvite, is high in the Newar community.
- Struvite production attracts general interest as sanitation option and fertilizer source.
- The effluent reuse is of major concern for the establishment of the process.



**Figure 4:** The 'pee-cycle' used to collect urine from a dozen households in the field study site's neighbourhood.

During the feasibility study, extensive surveys were conducted in a number of peri-urban settlements within the Kathmandu Valley. The research team established the contacts to the respective local administration and probed the support for a field study. Finally, the village of Siddhipur was chosen as the field study site, due to the high density of EcoSan toilets (> 100 toilets in use) and the close contact of UN-Habitat with the local Drinking Water and Sanitation Users Committee (see Figure 3 for a plan of the Kathmandu Valley with the location of Siddhipur).



**Figure 3:** Kathmandu Valley overview map with the location of Siddhipur, the STUN project's field study site.

### 2.3.2 Process development

#### 2.3.2.1 Process inputs

To collect urine for the struvite precipitation process, a bicycle was modified with a steel rack so that it could carry two 20 L plastic jerry cans securely beside the rear wheels (Figure 4). A cyclist rode the 'pee-cycle' and collected the urine from a dozen households in the village of Siddhipur. Approximately 250 L of urine were collected during one day and that quantity was sufficient for the research for a week.

To induce struvite precipitation from the hydrolyzed urine, magnesium is required. Since Nepal has no operational magnesium mines, bittern – the waste product from salt production – was imported from India. After salt (NaCl) is removed from seawater through evaporation, the remaining liquor contains about 2.6 % magnesium.

The use of bittern in struvite production has shown to be successful for other waste streams, such as landfill leachate (El Diwani et al, 2007; Lee et al, 2003) and could be

a way of reducing the waste produced in salt manufacturing. Refer to chapter 2.9.1.2 for details on bittern as a struvite precipitant.

Low quality (i.e. granular) industrial grade magnesium sulphate was also imported from a fertilizer company in Birganj (Rohit Chemicals P. Ltd.), located at the Nepali-Indian border. Magnesium sulphate is used as a magnesium fertilizer compound, though its importation into Nepal is not frequent. The various magnesium sources were analyzed for their magnesium content. In the case of magnesium sulphate, some heavy metal contamination was suspected, although it was not measured within the framework of this project.

To assure maximum precipitation, the magnesium was dosed at a molar ratio of 1.1:1 with respect to the measured phosphorus concentration in the reactor influent (stored urine). As the nutrient concentration in the collected urine varied greatly (from 170 to 320 mg·L<sup>-1</sup> PO<sub>4</sub>-P) the phosphorus content was determined prior to each precipitation experiment. Simultaneously, electric conductivity (EC) and pH were monitored.

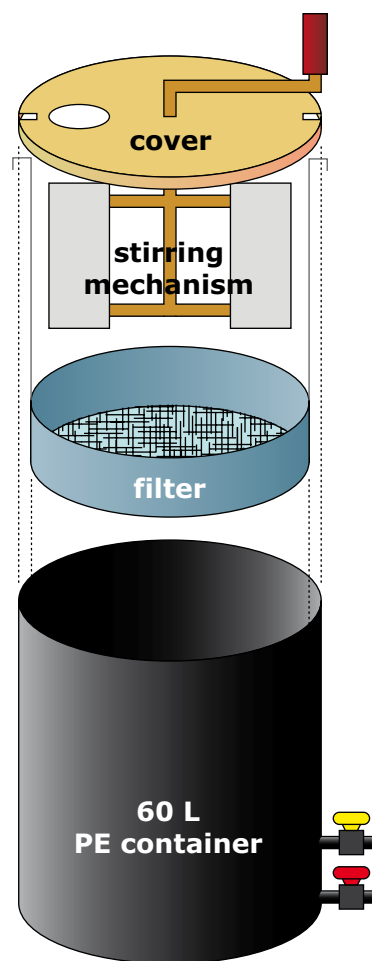
### 2.3.2.2 Reactor design

A first reactor was developed and tested at the field test site in Siddhipur. For the assembly of the reactor, the study emphasized a low-cost approach, entirely employing materials, which could be found at local hardware suppliers. Based on existing reactor designs for struvite recovery, a tank with a tapered bottom was required for the reactor set-up. In process technology, polyethylene (PE) or polypropylene (PP) would be the material of choice for such an installation. Since PE or PP cannot be formed or welded in Nepal, an alternative reactor version with a flat bottom and a lifting filter tray was used (Figure 5). The reactor tank was a modified PP drum, widely used for water storage throughout Nepal.

The operation of the reactor was assessed using phosphorus recovery as main indicator for efficiency (Etter, 2009). In this case, the phosphorus concentration of the process influent and effluent was compared. During the field test, the overall operation of the reactor was analyzed, in order to improve the user-friendliness of the process in an amended reactor version.

### 2.3.2.3 Process outputs

As a complementary study to struvite production, the reuse potential of the N-rich process effluent was explored (John Kashekya, 2009) with regard to ammonium volatilization and the risk of clogging in drip-irrigation systems (Barakoti, 2009). For future struvite and effluent applications, soil samples were taken on the field test site and guidelines for dosage will be elaborated (Maharjan, R., 2009).



**Figure 5:** The first STUN reactor featuring a PP drum, a welded stirring mechanism, and a lifting filter tray.

**Top:** Schematic drawing.

**Bottom:** View at the field study site.



## 2.4 Inputs from the evaluation of the previous project stages

The field study's first phase revealed the liquid-solid separation as the major weakness of the reactor prototype. Through the set-up with the filter tray, long sedimentation times (6 to 12 hours) were required. In addition, the crystals partially percolated besides the filter tray (through the gap between the tray's rim and the reactor's wall). Even though the precipitation efficiency reached high levels (> 95 %), only about half of the precipitated powder was finally recovered in the filter array. The powder settled, to a large extent, at the reactor's bottom (Figure 6), thus requiring frequent cleaning.

Concerning the magnesium source, a further potential for improvement was identified. As described below (refer to chapter 2.9.1), magnesium sulphate and bittern (the waste product from salt production) were used in the field tests. The company, which had provided a sample of bittern, indicated its interest in improving the process and increasing the magnesium concentration in its effluent, to reduce volume and weight of the substance shipped from the state of Gujarat in Western India. Nevertheless, if an adequate magnesium source could be found in Nepal, the process' cost and environmental impact could be minimized. In this aspect, a sample of magnesite rock from Nepal was analyzed to assess the mineral's potential as a local magnesium source (refer to chapter 5.2.1.2 for results on magnesite as magnesium source).



*Figure 6: Struvite powder sedimented at the reactor's bottom, due to low filter efficiency.*

## 2.5 Sanitary situation in the Kathmandu Valley

The rural exodus leading to rapidly growing cities and densely populated urban areas has made sanitation one of the main concerns of public health and environmental preservation. In traditional Nepal, scattered settlements in a mountainous region did not require any special treatment for human waste. Most people practiced and still practice open defecation, closing thereby the nutrient cycle at a most local level.

Many households still lack proper sanitary installations. In some peri-urban settlements, designated public defecation areas are available for the families, who do not have a toilet at their home. These public defecation areas consist mainly of a paved surface surrounded by a brick wall to guarantee the users a minimum of privacy for their business below the open sky.

Sewer systems are limited to the central metropolitan area of Kathmandu City, as well as parts of Lalitpur Sub-Metropolitan City. Historically, the Newar cities of Kathmandu and Lalitpur comprehended sophisticated drinking water supply, drainage and sewer systems comparable

to the ones found in the cities of the Roman Empire. The Newars conveyed their wastewater to vast infiltration beds at the outskirts of the city.

With the ongoing expansion of the cities, the sewer pipes have been extended to the banks of Bagmati River, which nowadays serves as main sewer for all of Greater Kathmandu. The heavy pollution of Bagmati has led to eutrophication of large areas and causes severe environmental and public health risks.

## 2.6 Phosphorus removal from wastewater streams

### 2.6.1 Conventional phosphorus elimination

In a conventional wastewater treatment plant, phosphorus elimination methods encompass biological treatment or precipitation through addition of multivalent metal salts (most common ions:  $\text{Ca}^{2+}$ ,  $\text{Al}^{3+}$ ,  $\text{Fe}^{3+}$ ) (Metcalf & Eddy, 2003). Whereas biological treatment usually demands a well controlled installation, constant oxygen, and balanced levels of nutrient (e.g. nitrogen), the chemical removal techniques are based on high inputs of precipitating agents and/or flocculants, hence elevated treatment costs. Furthermore, the precipitated P-metal compounds are barely soluble; their reuse as fertilizer is complex and energy-intensive.

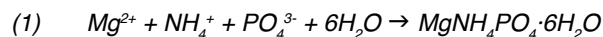
### 2.6.2 Phosphorus recovery from wastewater

The application of sewage sludge to crops has been the most common way of phosphorus recycling from wastewater streams. However, a more specific nutrient recycling has been envisaged to improve efficiency and to reduce negative impacts, caused through pollutants present in sewage sludge.

In the light of depleting phosphorus rock resources, recycling nutrients from wastewater has become increasingly interesting. Struvite precipitation from any phosphorus and nitrogen containing solution has long been known as a problem which causes clogging in sewer pipes. It was first studied with interest in nitrogen recovery by phosphate addition. Only recently, the naturally occurring reaction has been employed to harness phosphorus during the wastewater treatment process.

#### 2.6.2.1 Struvite precipitation

Struvite forms when magnesium reacts with the phosphate and ammonium contained in the urine, according to the following reaction formula:



As magnesium is present naturally in urine, and therefore in wastewater as well, struvite frequently precipitates in sewer pipes. The precipitation reaction can be triggered by adding magnesium in a soluble form to a phosphate and ammonium containing solution, and the struvite powder can be recovered thereafter by an adequate liquid-solid separation process. Given that struvite is least soluble in alkaline solutions (minimum solubility at pH = 9), stored urine is an ideal medium for precipitation, as its pH rises to above 8 by means of naturally occurring urea hydrolysis.

Heavy metals, pharmaceuticals and other organic contaminants, which have raised concerns in wastewater treatment, do not compromise the quality of struvite. More than 98% of pharmaceuticals and hormones remain in solution (process effluent), and possible heavy metal concentrations in struvite lie several orders of magnitudes below the concentrations detected in commercial fertilizers (Ronteltap et al., 2007)

In recent research projects, struvite has been recovered from diverse wastewater streams with varying efficiencies (refer to Table 1 for examples on achieved treatment efficiencies corresponding to various process influents). The Canadian company 'Ostara' has been operating a commercial scale struvite reactor at the wastewater treatment

**Table 1:** Research on struvite precipitation from various wastewater streams and corresponding removal rates.

wastewater origin	initial [ $\text{PO}_4\text{-P}$ ]	removal	source
	mg P/L	%	
Anaerobic digester supernatant I	133	86	Mavinic et al., 2007
Anaerobic digester supernatant II	84	82	Mavinic et al., 2007
Synthetic wastewater	22	78	Liu et al., 2008
Potato processing industry I	115	89	Moerman et al., 2009
Potato processing industry II	43	75	Moerman et al., 2009
Potato processing industry III	127	19*	Moerman et al., 2009
Dairy processing industry	64	73	Moerman et al., 2009
Stored urine	450	92	Tilley et al., 2008a
Treated swine liquid manure	13	77	Lee et al., 2003
Landfill leachate	43	91	Gunay et al., 2008

\* Interference with high  $\text{Ca}^{2+}$  concentration suspected

plant of the city of Edmonton AB (Canada). The reactor produces approximately 500 kg of struvite granules daily by treating 20 % of the treatment plant's digester supernatant (Ostara, 2009). After drying and packaging on-site, the struvite fertilizer is sold under the brand name 'CrystalGreen'.

### 2.6.2.2 Leaching from sewage sludge ash

Alternative technologies for phosphorus recovery from wastewater include leaching from sewage sludge ash. Ditrach et al. (2009) induced leaching of minerals from sewage sludge ash by hydrochloric acid addition. In a subsequent solvent extraction process, the dissolved minerals were isolated and concentrated, achieving phosphorus leaching rates of up to 85 %. The leachate also contained high concentrations of iron, aluminum, and calcium.

### 2.6.2.3 Adsorption

Biswas et al. (2008) ran experiments on phosphorus adsorption using orange waste (issued from orange juice production) immobilized with zirconium  $Zr^{4+}$  and prepared as gel. After adsorption, the phosphorus was eluted from the gel using a sodium hydroxide solution; the gel showed to be fully recyclable in the process. The advantage of the process lies in its broad range of operational pH: from pH = 2 to 9, phosphorus recovery exceeded 85 %.

Phosphorus adsorption on minerals (e.g. ferric hydroxide, aluminium oxide) has been studied extensively. After adsorption, the phosphorus can partly be recovered by use of NaOH (Genz et al., 2004). Various experiments have been carried out to enhance the nutrient recovery from urine using adsorbing minerals, such as zeolite or wollastonite (Lind et al., 2000). Through adsorption (by ion exchange), nitrogen recovery could be increased to 65-80 % (ibid.), compared to typically 3 % by simple struvite precipitation.

## 2.6.3 Nutrient recovery from urine

### 2.6.3.1 Direct application of urine

Urine may be applied to crops as a fertilizer, where the dissolved nutrient ions are readily assimilated by the plants. In practice, urine is often diluted with water, to prevent over-application. Dilution ranges from 1:1 to 1:10 (volume urine:volume water); 1:3 seems to be common (Jönsson et al., 2004).

In an attempt to close nutrient cycles locally, direct urine application is preferable. Nevertheless, if urine cannot be applied directly to crops, as the distance between urine producing and fertilizer demanding sites increases, an option for nutrient concentration has to be elaborated. In addition, ammonium volatilization leads to nutrient loss

and eutrophication issues, when urine is applied directly.

The urine diverting dry toilets (UDDT), known as EcoSan toilets, promoted throughout Nepal by various NGOs, such as UN-Habitat, ENPHO, CIUD, D-Net, integrate the concept of local nutrient recycling into their basic principles. According to EcoSan promoters, UDDT not only provide sanitary facilities to deprived populations, but add an extra value to excreta, and reduce dependency on supplementary (i.e. costly) agricultural inputs.

### 2.6.3.2 Struvite precipitation

Whereas several substances are known to react with phosphorus contained in urine and form precipitates (predominantly struvite  $MgNH_4PO_4 \cdot 6H_2O$  and hydroxyapatite, HAP,  $Ca_{10}(PO_4)_6(OH)_2$  [Udert et al., 2003]), only struvite precipitation has been studied in the scope of nutrient recovery (Maurer et al., 2006) from wastewater streams (refer to chapter 2.6.2.1 for details on the precipitation reaction). The process has been applied to anaerobic digester supernatants (Mavinic et al., 2007), but can equally be adapted to source separated urine as phosphorus source (Tilley et al., 2008a; Wilsenach et al., 2007).

### 2.6.3.3 Other processes

Maurer et al. (2006) compiled an overview on treatment processes for source separated urine. Besides struvite precipitation, the most important nutrient recovery processes include ammonia stripping and electro dialysis.

Attempts to recover nitrogen from urine have been made with ammonium stripping (Behrendt et al., 2001): the stripped gas was adsorbed in acid, although the final product was not stable at normal pressure. As in fresh urine, nitrogen is predominantly present as urea  $CO(NH_2)_2$ , the nutrient can be removed by complexation with isobutyraldehyde (IBU), forming isobutyraldehyde-diurea (IBDU). Though, high urea concentrations (approx. 1 %) and high excess IBU concentration is necessary, wherefore the process has not been adopted for industrial production (Behrendt et al., 2001; Reinhart, 2002).

By using electro dialysis, nutrients can be concentrated and micropollutants can be retained to a certain extent (Pronk et al. 2006). In a comparison, Ek et al. (2006) recovered phosphorus and other nutrients from urine by reverse osmosis RO, evaporation, drying, and struvite precipitation. Although more than 90 % of phosphorus was withheld by the RO membrane, the researchers announced concerns on membrane fouling due to calcium or struvite precipitation, which reduces the potential for commercial applications. In fact, 1 m<sup>3</sup> urine treated with RO produced 800 L permeate containing mainly nitrogen and 200 L concentrate containing 90 % of phosphorus and lower nitrogen concentrations, as well as other salts and organic pollutants.

## 2.7 Liquid-solid separation in wastewater treatment

### 2.7.3.1 Sedimentation and flotation

Because most industrial processes operate on continuous flow, liquid-solid separation primarily resorts to density difference as driving force. Solids, which are to be separated from the liquid, either float at the surface or settle at the bottom of a reactor. Hence, numerous struvite precipitation processes – from laboratory to industrial scale – purge the struvite crystals through a settling zone at the reactor's lower extremity.

In a given liquid-solid separation process, particle size is the only parameter to accelerate sedimentation velocity (based on Stokes' Law; viscosity, as well as the density of the liquid and the solid are inherent to the process). For an efficient sedimentation, particles have to reach a certain size. Therefore, flocculation by means of flocculant addition can enhance process efficiency (refer to chapter 2.8 for details on flocculants in wastewater treatment and struvite precipitation in particular).

### 2.7.3.2 Filtering

A pilot scale struvite precipitation reactor set up by Huber Technology (Hans Huber AG, Maschinen- und Anlagenbau, Berching, Germany), operates with a fleece bag as the filter (Huber, 2006). Following the magnesium addition and mixing, the precipitated struvite is left to settle at the conical reactor bottom. The supernatant is decanted before the concentrated suspension is drained through the lower central outlet and filtered in the below-lying fleece bag (WIPO, 2006).

The first STUN struvite precipitation reactor constructed in Siddhipur, was inspired by a century old liquid-solid separation technology: during the process of cheese production, the curd is separated from the whey by immersing a cloth in the cauldron and lifting it up to drain the remaining liquid. Analogically, the precipitated struvite at the first STUN reactor's bottom was separated by lifting the filter tray out of the liquid.

Since the liquid-solid separation showed to be a drawback of the STUN reactor's first version, the tray-lifting technique was abandoned during the conception of the second reactor. The process developed by Huber Technology has been tested at pilot scale in collaboration with Eawag. Therefore, a filter bag design was selected for the second improved STUN reactor in Nepal.

Filtering is a complex process involving various mechanisms; apart from filter pore size, filter cake accumulation on the filter's surface or adsorption on the filter material may play an important role in solid retention. Different filter materials have to be assessed regarding their performance by testing them in a realistic setting. Analogous

to sedimentation, an increased particle size will also enhance filter efficiency.

To remove phosphorus from liquid swine manure, Szögi et al. (2006) induced coagulation by lime ( $\text{Ca}(\text{OH})_2$ ) addition, and subsequent filtering through non-woven polypropylene and monofilament filter bags at pilot scale. The filtering was only effective with the addition of a polyacrylamide (PAM) polymer treatment, to prevent clogging and incomplete filtration.

### 2.7.3.3 Enhancing process efficiency through increased particle size

Both in sedimentation and filtering, bigger particles can be recovered from liquids with increased efficiency. Current research in struvite precipitation has focused on the enhancement of crystal size. Commercial applications are based on up-flow reactors featuring fluid recycling; the crystal nuclei are recycled, as long as their size does not reach a sufficient level to precipitate. The struvite crystals harvested from the Ostara reactor operated at the wastewater treatment plant in Edmonton AB, Canada attain diameters of up to 240 SGN (size guide number), i.e. 2.4 mm median granule diameter (Ostara, 2009).

Crystal formation is based on two principal kinetic processes (Gnielinski et al., 2003):

1. **Nucleation:** formation of condensation nuclei induced by super-saturation. Nuclei may already be present in the solution in the form of any particulate matter.
2. **Crystal growth:** ions are added to the nuclei's surface, augmenting particle size.

Elevated super-saturation ratios increase both crystal growth velocity and nucleation rate. At a high initial super-saturation ratio, nucleation will be favoured, producing thus numerous fine crystals. In order to obtain maximum crystal size in struvite precipitation, magnesium has to be added at a slow continuous rate, although in lab experiments (Hausherr, 2004) continuous magnesium addition over 205 minutes instead of 15 minutes increased mean crystal size by only 48 %.

In urine, naturally present particles play an essential role in crystal formation (Hausherr, 2004). In general, struvite has to be assumed to undergo rapid morphologic changes through constant aggregation and disaggregation processes. It is therefore difficult to predict particle size in a pilot or real scale process based on lab measurements.

### 2.7.1 Filter materials available in Nepal

In order to maintain a broad accessibility for future applications of the STUN process, widely available filter materials were chosen for testing. Normal nylon or cotton fabric can be found in any tailor store at comparably low rates (50 NRs·m<sup>-2</sup>; ca. 0.50 €·m<sup>-2</sup>). Densely woven nylon or coated nylon fabric is available at any of the numerous outdoor equipment stores in Kathmandu.

Nepal is famous for its handcrafted paper production, using the local lokta tree (*daphne papyracea*) as a renewable raw material. Paper products of varying weight (e.g. 100, 250, 500 g·m<sup>-2</sup>) are thus available, and can be used for filtering.

### 2.7.2 Tested filter materials during previous project stages

The first STUN reactor (with lifting filter tray) employed two different filter arrays (Figure 7):

1. Cotton fabric on a welded steel and wire mesh assembly. Sheet metal rim with a height of 5 cm.
2. Common nylon fabric sewn to an iron ring (welded 8 mm iron bar).

Both filters set-ups showed a poor solid removal rate of barely 50 % (Etter, 2009) according to a comparison of the mass of struvite retained and the mass of potential struvite formation calculated based on the phosphorus concentration difference between the reactor influent and effluent. First, it was concluded that the mesh size of the

fabrics was too large. However, more in-depth analyses revealed that other factors were more important for the low apparent struvite recovery:

- Part of the settling struvite percolated through the gap between the filter tray and the reactor's wall, thereby settling directly at the reactor's bottom. Especially in the case of the nylon fabric filter tray with the low rim, the flow of struvite by-passing the filter reduced the removal efficiency considerably.
- When lifting the tray, a portion of the remaining suspension was spilt over the filter's rim.
- The mass balance of struvite lacks precision, as struvite is a highly dynamic mineral with various hydration states and intermediate complexes. Its composition will change according to environmental conditions, e.g. air moisture content or temperature. If struvite is heated above 55 °C, gradual water and ammonium loss will produce amorphous magnesium hydrogen phosphate (MgHPO<sub>4</sub>) as a final compound (Bhuiyan et al., 2008). Considering that the struvite was dried in the sun, a partial volatilization of ammonium has to be suspected, thus decreasing the mass of the recovered powder. The measured mass cannot be attributed to a specific chemical formula, as long as the substance is not closely examined.

The slow settling speed of the produced struvite (> 24 h for 40 cm settling depth), especially during the cold winter period, led to the conclusion that an improved reactor should resort to complete filtration of the urine-struvite suspension, without prior decantation.



**Figure 7:** The 2 tested filter arrays in the first STUN reactor. **Left:** cotton fabric ( $d_{\text{pore}} < 200 \mu\text{m}$ ) on a welded steel and wire mesh assembly. **Right:** nylon fabric ( $d_{\text{pore}} < 100 \mu\text{m}$ ) sewn to an iron ring.

## 2.8 Coagulation and flocculation in wastewater treatment

### 2.8.2.1 Inorganic metal salts coagulants

Most frequently used mineral coagulants in wastewater treatment include aluminium sulphate (alum,  $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ ), ferric chloride ( $\text{FeCl}_3$ ) or ferric sulphate ( $\text{Fe}_2(\text{SO}_4)_3$ ). However, the coagulation process using these metal salts is strongly linked to pH; if applied in struvite precipitation from urine, the high pH in stored urine (typically pH = 9) may inhibit the coagulating function (optimum condition for phosphorus precipitation using alum as coagulant: pH = 5 to 6 [Georgantas et al., 2007]).

Coagulation of a metal phosphate precipitate combined with filtering through geotextiles was examined by Sharer et al. (2009). A synthetic polymer flocculation aid (HyChem CE 1950 at  $25 \text{ mg} \cdot \text{L}^{-1}$ ) was also added to an aquaculture effluent. Total phosphorus removal achieved 67.6, 47.0, and 77.3 % for alum, ferric chloride, and lime as coagulant respectively.

If the process aims to produce input products for agriculture, availability or eventual toxicity for crops should also be taken into account. Solubility of iron-phosphate compounds is very low; hence release is extremely slow, and nutrients cannot be readily assimilated by plants (Roy et al., 2006). Aluminium is only beneficial for a few crops, e.g. tea, though it acts as a strong soil acidifier. For most crops, aluminium is toxic (ibid.). Alum addition for struvite production may thus only be an option in the tea growing regions of Eastern Nepal.

### 2.8.2.2 Synthetic long-chain polymers

Long-chain organic molecules bridge inter-particle space in a suspension by attaching to adsorption sites on the surface of particles in suspension (Metcalf & Eddy, 2003). Numerous commercial products are available for applications in wastewater treatment. According to the nature of the suspended matter, either cationic or anionic flocculants may show preferable results (refer to section below for specifications on flocculation in struvite recovery).

When testing non-woven polypropylene and monofilament filter bags for phosphorus removal from swine manure using lime ( $\text{Ca}(\text{OH})_2$ ) as coagulant, Szögi et al. (2006) found that filtering was only effective, if a synthetic polyacrylamide (PAM) flocculant was added. In the comparison of anionic and cationic PAM at various rates, only the anionic PAM was effective, with best results obtained at a dose of  $30 \text{ mg} \cdot \text{L}^{-1}$ .

Although synthetic polymer flocculants has a beneficial effect on water treatment efficiency, their use can have negative environmental impacts, as toxic by-products may form (Bratby et al., 2007). Renault et al. (2008) there-

fore plead for the use of natural polymers, as described in the following paragraph.

### 2.8.2.3 Natural polymers – chitosan

As an alternative to synthetic polymers, natural polymers have been known, respectively 'rediscovered', as flocculants for water or wastewater treatment. Chitosan is a linear copolymer extracted from chitin, the main compound in the exoskeleton of marine crustaceans. Chitosan has numerous applications in water and wastewater treatment, given the following characteristics (Renault, 2008):

- Non-toxic
- Biodegradable
- Renewable resource
- Ecologically acceptable polymer
- Efficient against bacteria, viruses, fungi
- Formation of salts with organic and inorganic acids
- Ability to form hydrogen bonds intermolecularly
- Ability to encapsulate

Chitosan's potential applications include (ibid.):

- Flocculant to clarify water (drinking water, pools)
- Reduction of turbidity in food processing effluents
- Coagulation of suspended solids, mineral & organic
- Flocculation of bacterial suspensions
- Interactions with negatively charged molecules
- Recovery of valuable products (proteins...)
- Chelation of metal ions
- Removal of dye molecules by adsorption processes
- Reduction of odours
- Sludge treatment
- Filtration and separation
- Polymer assisted ultrafiltration

Renault et al. (2008) compiled data on diverse treatment processes where chitosan was successfully employed as a flocculant (e.g. organic matter, humic substances, dye molecules, metal cations, proteins, phenolic and aromatic derivatives, oil and grease, bacterial and algal suspensions), though no literature concerning phosphorus removal is available.

#### 2.8.2.4 Natural polymers – moringa

The moringa oleifera tree has various beneficial properties; it thrives well in dry regions, its fruits and leaves are highly nutritional and its seeds are known to contain a protein, which acts as natural coagulant/flocculant. The coagulating/flocculating protein is found in the oil cake, i.e. it is still available after extraction of the edible oil (up to 40 % of the seeds mass).

Bhuptawat et al. (2006) report a 50 % overall COD removal in wastewater treated with 50 to 100 mg·L<sup>-1</sup> (dry weight) ground moringa seeds in a laboratory set-up featuring a column sand filter. This removal rate could be increased to 58 respectively 64 %, if the moringa doses were applied in combination with 10 mg·L<sup>-1</sup> alum (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·18H<sub>2</sub>O) powder.

With regard to drinking water treatment, Lohri (2009) compared moringa-induced coagulation/flocculation of mineral and organic pollutants. To analyze mineral pollution, unwashed sand was added to tap water and left to settle. The decanted liquid containing fine particles in suspension was then treated with ground moringa seeds at various doses (100, 250, and 500 mg·L<sup>-1</sup>), and turbidity (NTU) was measured as an indicator for suspended solids (SS) removal.

To study the removal of organic pollution, soil substrate was added to the tap water. Although the moringa seeds

did not affect the mineral pollution, they produced a decrease of turbidity to approximately 20 NTU after 4 hours sedimentation, compared to 85 to 120 NTU obtained in the untreated sample.

### 2.8.1 Flocculation in struvite recovery

Application of flocculants and/or coagulants in struvite recovery was explored by Le Corre et al. (2007). Destabilization of fine particles to promote the growth of larger crystals was achieved with the addition of alum, ferric chloride and sulphate, or a cationic polymer (polyDADMAC).

Coagulation/flocculation tests in 1 L jars and particle size analysis using a laser granulometer revealed that the highest particle size (as d<sub>0.5</sub>) increment was obtained by polyDADMAC addition, though this flocculant also showed to be the most pH sensitive. At pH = 9, polyDADMAC produced tenfold particle size.

### 2.8.2 Flocculants available in Nepal

Table 2 presents a list of flocculants and precipitants found in Nepal. Despite of its high potential in wastewater treatment, chitosan was not available in Nepal. The reasons why chitosan is not available in Nepal may include:

- Nepal is a landlocked country, hence transportation for any product of marine origin is difficult.
- A market for flocculants has not emerged yet in a region, where wastewater treatment is limited to basic applications.

However, as wastewater treatment will gain importance, new distribution channels for chitosan might evolve.

**Table 2:** Potential flocculants and precipitants available in Nepal:

Name	Price	Description
	NRS·kg <sup>-1</sup>	
Alum (Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·18H <sub>2</sub> O) फुटगिरी (phuṭgiri)	50	Can be found on any market in Nepal, as it is widely used for its anti-bacterial properties in barbershops. Aluminium toxicity affects numerous crops, the use of alum thus has to be restricted to areas, where aluminium can be applied in agriculture without compromising plant growth (e.g. tea plants require aluminium as nutrient).
Lime (Ca(OH) <sub>2</sub> ) चून् (chūn)	25	Is widely available for construction purposes (not to be confused with agricultural lime).
Moringa oleifera सजिवन (sajivan)*	50	The moringa tree grows in the Tarai region (southern lowlands in Nepal), as well as in the adjacent Indian states. Although the fruits are known to be edible, they have not reached their full potential as a food crop. Other products, such as oil extracted from the moringa seeds, are barely known in Nepal, but are increasingly promoted in Northern India.

\* caution: in Nepali, the term sajiwan is also widely used for *jatropha curcas*, a plant cultivated for the production of bio-diesel, and promoted by the government of Nepal.

## 2.9 Magnesium sources used for struvite recovery

### 2.9.2.1 Factors influencing the suitability of magnesium sources

The suitability of a magnesium source for struvite production depends on the following parameters:

- **Solubility:** For efficient struvite precipitation, the magnesium salts should readily dissolve when added to the urine or the magnesium should be available as a solution. If solubility is too low, pre-treatment of the magnesium source will be necessary, adding additional cost to the overall process.
- **Price:** For competitive production, the input costs have to be minimized.
- **Concentration:** High magnesium concentration decreases weight and volume, and therefore transportation energy and cost.
- **Side products:** If the magnesium source has to be pre-processed (e.g. with acids) to adapt its solubility to the struvite production, the arising waste-products should be disposable without negative impact on the environment.
- **Sustainability:** All mineral resources are non-renewable, availability and prices are thus likely to change in the prospects of depletion.
- **Handling:** For a simple struvite production process, the magnesium dosage to the reactor should not involve any special preparation (if possible use magnesium source directly as powder or solution).

### 2.9.2.2 Characteristics of magnesium sources

Various magnesium sources have been tested and employed for struvite precipitation at different scales:

- **MgCl<sub>2</sub>:** Is the most widely used precipitant in struvite production, available in powder form for laboratory applications as well as for large scale industrial operations (Liu et al., 2008; Moerman et al., 2009; Pastor et al., 2008; Ronteltap et al., 2007; Wilsenach et al., 2007). As a powder in hydrated form: MgCl<sub>2</sub>·6H<sub>2</sub>O. MgCl<sub>2</sub> is found in solution in the effluent of salt production from seawater (Venkataraman, 2009) (refer to the section on bittern for details).
- **MgO:** Mostly limited to lab scale applications. (Wilsenach et al., 2007)
- **MgSO<sub>4</sub>:** Available as combined Mg<sup>2+</sup> and SO<sub>4</sub><sup>2-</sup> fertilizer. Used during the 1<sup>st</sup> STUN phase, given its availability in Nepal. As a powder in hydrated form: MgSO<sub>4</sub>·7H<sub>2</sub>O.
- **Bittern:** Salt brine issued from salt (NaCl) production from seawater (refer to chapter 5.2.1.1 for description of production process). (El Diwani et al., 2007; Lee et al., 2003). Bittern can be obtained from the salt production located in the Indian state of Gujarat (Western India).
- **Magnesite:** Found as rock deposits. Has to be processed prior to use as precipitant, given its low solubility (Gunay et al., 2008). May contain other minerals, such as silicon or aluminium.

**Table 3:** Characteristics of magnesium sources for struvite production:

compound name	magnesium component	molecular weight <i>g·mol<sup>-1</sup></i>	gravimetric Mg content %	molar Mg content <i>mol·kg<sup>-1</sup></i>	required Mg input* <i>kg·kg<sup>-1</sup></i>
magnesium	Mg	24.3	100.0	41.15	0.10
magnesium chloride hexahydrate	MgCl <sub>2</sub> ·6H <sub>2</sub> O	203.3	12.0	4.92	0.83
magnesium sulfate heptahydrate	MgSO <sub>4</sub> ·7H <sub>2</sub> O	246.5	9.9	4.06	1.00
magnesite	MgCO <sub>3</sub>	84.3	27.4	11.27	0.36
dolomite	(Ca,Mg)CO <sub>3</sub>	84.3	11.5	4.74	0.86
magnesium oxide	MgO	40.0	60.8	25.00	0.16
magnesium hydroxide	Mg(OH) <sub>2</sub>	58.3	41.7	17.15	0.24

\* kg magnesium compound per kg struvite produced, based on a molar ratio of Mg:P = 1:1

### 2.9.1 Magnesium sources available in Nepal

There has not been any market for magnesium in Nepal, therefore the import of magnesium is limited to a strict minimum. However, after extensive research during the first project phase, the STUN project was able to identify two potential magnesium sources: magnesium sulphate and bittern. Both magnesium sources could be purchased locally in sufficient amounts to conduct experiments.

#### 2.9.1.1 Magnesium sulphate

Magnesium sulphate is used and marketed as a fertilizer in India, though it is not readily available in Nepal. After a lengthy bureaucratic procedure, a 50 kg bag of magnesium sulphate was imported by Rohit Chemical Traders in Birganj at the Indian border at a price of 40 NRs·kg<sup>-1</sup>. As the performance of the obtained magnesium sulphate in struvite precipitation was not as high as expected, a sample of the fertilizer powder was sent to the Eawag lab for analysis (refer to chapter 5.2.2.1). The first STUN reactor produced 85 % precipitation efficiency if operated with magnesium sulphate, whereas up to 96 % precipitation efficiency were achieved when using bittern.

#### 2.9.1.2 Bittern

During the 1<sup>st</sup> phase of the STUN project, a sample of salt brine produced by the Jakhau Salt Company (Kutch, State of Gujarat, India) was analyzed for its mineral content (Table 4). Compared to magnesium sulphate, the bittern showed higher precipitation efficiency, which may be due to the following factors:

- In bittern, magnesium is already in solution, ions are thus readily available for the precipitation reaction.
- The magnesium sulphate was found to be of low quality, containing only 5 % Mg (instead of 10 % potential magnesium content).

According to the representative of the supplier (Jakhau Salt Company, Kutch, Gujarat, India), bittern can be obtained at varying grades of concentration. If desired, a solution containing higher magnesium concentrations can be produced by a further process step in the salt production (refer to chapter 5.2.2.2 for a description of the salt production process and an outlook on potential linkages to struvite production).

**Table 4:** Mineral concentrations in bittern from Jakhau Salt Company, Kutch, Gujarat, India.

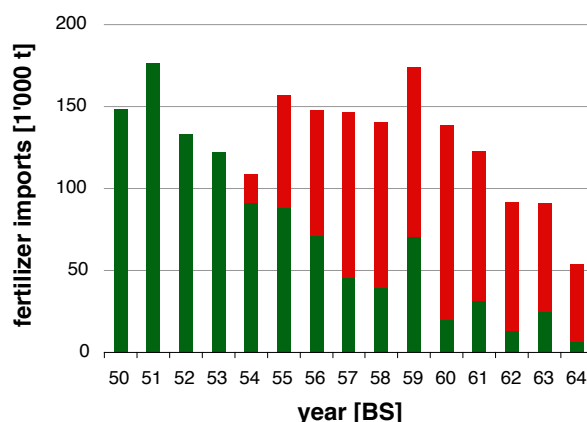
Parameter	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	dry residue
Unit	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>
Method	IC	IC	ICP	ICP	ICP	ICP	
Value	17'380	3'280	27'524	223	9'848	70'861	129'115

## 2.10 Evolution of the fertilizer market in Nepal

### 2.10.1.1 Illegally imported fertilizer from India

In an attempt to boost agricultural production, the Indian government has heavily subsidized fertilizers throughout the country. In addition, the fertilizer market prices have been frozen at their 2002 level, with present subsidies arising to an estimated 1 trillion INR (16 billion €) per annum (Sakthivel, 2009). Along the Indo-Nepalese border illegal fertilizer trade has thrived. At present, 1 kg of urea is available at a rate of 8 NRs·kg<sup>-1</sup> (0.08 €·kg<sup>-1</sup>) in the Nepalese border towns; if subsidies were inexistent this price would rise to an estimated 58 NRs·kg<sup>-1</sup> (0.58 €·kg<sup>-1</sup>) (Gautam, 2008). However, the rate of 8 NRs·kg<sup>-1</sup> near the border increases to 24 NRs·kg<sup>-1</sup> in the Kathmandu Valley.

Previous to the change in Indian agricultural politics, all fertilizer imports into Nepal were controlled by the government run Agricultural Input Company AIC. Figure 8 shows the fading control over fertilizer imports by the Nepalese government.



**Figure 8:** Share of public and private (mostly informal) fertilizers imports into Nepal from 2050 to 2064 BS. (data: MoAC, 2008, graph: STUN). BS = AD + 56.7 a.

■ AIC (government) ■ private

Despite of the government controlled prices in India, end of the chain fertilizer prices in Nepal have been subject to major uncertainties, during 2008 AD due in part to the world economic crisis, and, as some people allege, due to China restricting its international trade during the Olympic Games. According to the Nepalese Ministry for Agriculture and Cooperatives MoAC (2008), fertilizer sales have declined with augmenting prices (Figure 9).

### 2.10.1.2 Future scenarios

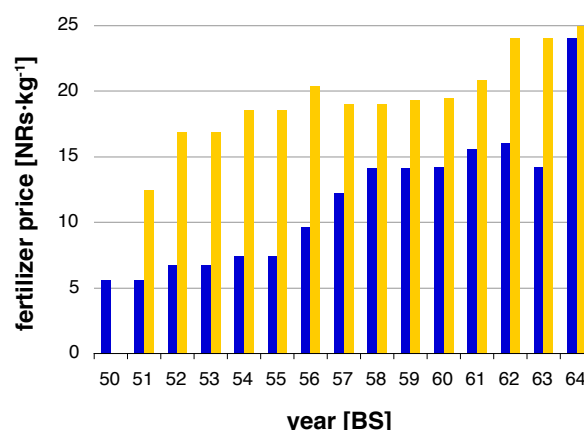
Numerous factors will influence the availability of fertilizers in Nepal in the future. The majority of scenarios indicate a further price hike and some considerations even signal a manifold increase in prices:

- The Indian government has launched a new programme with the aim to cut down on illegal fertilizer trade across the border to Nepal (Chopra, 2009). Police checks shall be intensified along the border and fertilizer sales will not be possible within a certain distance from the border.
- Current phosphorus mineral reserves are projected to be depleted within a few decades. The currently exploited deposits suffer from a diminishing quality and reduced accessibility. Global trends indicate a strong increase in prices of phosphate containing rocks (Cordell et al. 2009).
- The Nepalese government announced a new programme of state fertilizer sales in Nepal (The Himalayan Times, 2009). The AIC has posted a tender on 13 May 2009 for 12'500 t urea and 12'500 t DAP, calling for offers from worldwide fertilizer traders. According to the government plan, fertilizer shall be sold at 25 % higher price than in India, in order to prevent sale of Nepalese fertilizer to India, and to cut down on illegal imports from India, as Indian fertilizer at a subsidized rate plus the transport expenditures will equal the higher price.

### 2.10.1.3 Organic fertilizers

With increasing awareness of the negative impacts of chemical use in agriculture, the demand for organically grown products has been set in motion in Nepal like in many other countries. At present, organic fertilizers are being commercialized by various companies with growing sales volumes (Ghimire, 2009), although no detailed figures are available.

On-farm nutrient recycling is promoted by numerous NGOs (e.g. ICIMOD, SSMP, ENPHO etc.) as alternative to external inputs. ICIMOD promotes the so-called "Plant Tonic" (Figure 10), which consists of cow urine and cow dung mixed with *eupatorium*, yeast and salt (Sherpa, 2009).



**Figure 9:** Fertilizer prices in NRs·kg<sup>-1</sup> for urea and DAP in Nepal from 2050 to 2064 BS. (data: MoAC, 2008, graph: STUN). BS = AD + 56.7 a.

■ urea                      ■ DAP

Locally known for its nutrient content, the oil or press cake (Nepali: पिना) issued from mustard (*brassica campestris*) oil production is occasionally applied as fertilizer to crops (Maharjan, J., 2009). It is also used as animal feed (in live stock breeding or pisciculture) as a protein supplement. Only few publications are available on the use and the exact nutrient content of the oil cake, some stating its NPK value at 5:1.8:1 (Dhruv et al., 2008) or its phosphorus concentration at 0.97 % P (0.97 % as P corresponds to 1.7 % as P<sub>2</sub>O<sub>5</sub> as expressed in NPK) (Tiwari et al., 2006).



**Figure 10:** "Plant tonic", a natural fertilizer mix promoted by ICIMOD at its training and demonstration site in Godawari.

# 3 Objectives

*Optimize the technology  
for low-cost struvite  
recovery and prepare it for  
dissemination*

After the preliminary feasibility study, the STUN project focused on the technological aspects of struvite precipitation. As the first prototype struvite precipitation reactor performed only with a restricted removal efficiency, this study aims at optimizing low-cost struvite recovery:

1. *Optimize liquid-solid separation:*

- Comparison of filters.
- Examination of sedimentation velocity of struvite.
- Testing of the effect of flocculants on recovery efficiency and sedimentation velocity.
- Development of a new improved reactor.

2. *Select an ideal Mg source, transport, and processing:*

- Comparison of availability and price.
- Evaluation of the magnesium content.
- Assessment of necessary pre-treatment.

3. *Integrate pre- and post-process options into the analysis, to develop an user-friendly process.*

- Assess potential urine harvesting sites.
- Experiment with granulation of struvite powder.

Based on the above mentioned objectives, the following research questions were developed:

1. *Liquid-solid separation:*

- Which filter is the most adapted in terms of removal efficiency, availability, and cost-efficiency?
- Can soil texture determination methods be used to determine sedimentation velocity of struvite?
- What is the effect of flocculants on sedimentation velocity and filter efficiency?
- How can the findings be employed in an improved struvite precipitation reactor?

2. *Magnesium source:*

- Which magnesium source is most adapted in terms of precipitation rate, availability, cost-efficiency, and handling?
- How high is the magnesium concentration in the selected substances?
- What kind of pre-treatment is necessary to produce magnesium for struvite precipitation?

3. *Process setting:*

- Which locations will be suitable for a future up-scaled version of the STUN process?
- Is it possible to produce user-friendly granules of struvite?

Through these research questions, the technological optimization of the STUN process shall be completed by this MSc thesis. Ideally, the outcome of the present report will make the process ready for dissemination.

# 4 Methodology

*Combining laboratory and  
field methods for the design  
of an optimized struvite  
precipitation reactor*

The results from the operation of the first pilot scale struvite precipitation reactor (see project intermediate report for details: Etter, 2009) presented the basics for the further proceedings in the project. The development of the STUN process followed therefore an iterative approach, gradually improving the various parameters involved in the process. In the subsequent paragraphs, an overview of the employed methods will be presented, structured according to the strategies selected for the process optimization (not necessarily following a chronological order).

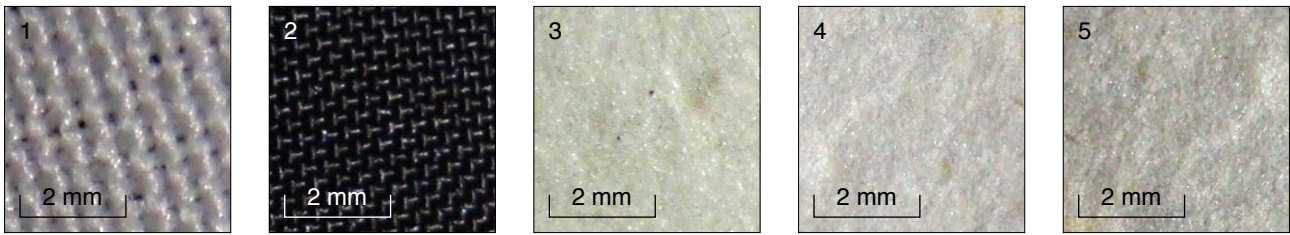
## 4.1 Optimization of liquid-solid separation

### 4.1.1 Comparison of filter designs and materials

#### 4.1.1.1 Lab tests of filter materials

Five different filter materials (see Figure 11) were compared in a laboratory study carried out at the Aquatic Ecology Centre (AEC) of the Kathmandu University (KU) located in Dhulikhel, Kavrepalanchok District (35 km East of Kathmandu). Struvite precipitation was induced in 1 L of urine by adding 10 mL bittern (270 mg magnesium). The filter materials were cut into 150 mm filter discs, and inserted into a ceramic filter holder. After 10 minutes of mixing, using a magnetic stirrer set at approximately 200 rpm, 100 mL of the well mixed urine-struvite suspension was filtered through 2 replicates of each filter disc.

The permeability of the filter was assessed by comparing both phosphate concentration and total solids (TS) in the initial suspension and the filtrate. To determine TS, the liquid samples were dried at 105 °C during 24 hours and then weighed using an electronic scale ( $\pm 0.1$  mg). To dissolve struvite particles in suspension and measure the total phosphate, 1 M of HCl was added to the samples prior to preparation for the photo-spectrometric analysis (refer to chapter 4.4.1 on phosphate measurements).



**Figure 11:** Five different filter materials were compared for their struvite recovery efficiency at laboratory scale: 1. cotton fabric ( $d_{\text{pore}} < 200 \mu\text{m}$ ), 2. nylon fabric ( $d_{\text{pore}} < 100 \mu\text{m}$ ), 3. nepali paper (weight  $50 \text{ g}\cdot\text{m}^{-2}$ ), 4. nepali paper (weight  $70 \text{ g}\cdot\text{m}^{-2}$ ), 5. nepali paper (weight  $110 \text{ g}\cdot\text{m}^{-2}$ ).

#### 4.1.1.2 Field tests on filter designs

The filter design used in the first reactor had shown a poor performance with respect to solid retention. As the laboratory tests had proved that the filter material's inherent filter efficiency was sufficient, the filter design in the second reactor version was re-designed. Instead of a lifting filter tray, as used in the first reactor, the second reactor was fitted with a cloth filter bag attached to its lower central outlet. During the tests on the first reactor, the struvite powder had percolated between the filter's rim and the reactor's wall, and part of the settled struvite had also been spilt, when lifting the filter tray out of the reactor tank.

The tests on filter efficiency in the field were carried out the same way as the laboratory tests: the acidified samples (by addition of 1 M HCl) of both reactor influent and effluent were compared for their phosphate concentration (refer to chapter 4.4.1 on phosphate measurements). The total time necessary for filtering the 50 L content of the reactor was recorded, to assess the clogging of the filter. Two nylon filter bags were tested for their performance (Figure 12).



**Figure 12:** Two filter bags tested for their performance: **Left:** Rectangular shape with approximately  $1500 \text{ cm}^2$  filtering surface; **Right:** Cylindrical shape with approximately  $2000 \text{ cm}^2$  filtering surface.

#### 4.1.1.3 Field tests on filter cake buildup

As the filter cake buildup on the filter fabric's surface was considered more important than the effective pore size for the filtering process itself, the phosphate concentration contained in the effluent was measured over time in intervals of 0,1,2,5,10, and 20 minutes from the opening of the reactor's lower outlet valve. Simultaneously, the accumulated filtered liquid volume was recorded, in order to allow subsequent integration of the percolated phosphorus mass.

#### 4.1.2 Examination of granulometric distribution and sedimentation velocity of struvite

In soil analysis, particle size distribution for particles smaller than 0.05 mm (which corresponds to the lowest particle diameter defined as sand) is determined by means of sedimentation by either the hydrometer or pipette method of direct solution sampling (Or et al., 2007). The sedimentation velocity  $V_s$  is related to the particle size by Stokes' Law (Equation 2) at a given temperature (usually  $25^\circ\text{C}$ ).

$$(2) \quad V_s = 2 (\rho_p - \rho_f) \cdot g \cdot R^2 / 9\mu$$

- $V_s$  particle settling velocity
- $g$  gravitational acceleration
- $\rho_p$  particle density
- $\rho_f$  fluid density
- $\mu$  fluid dynamic viscosity
- $R$  radius of a spherical particle

The suspension is left to settle in a 1 L glass column. At a given time and a given depth, the largest remaining particle diameter can be calculated employing Stokes' Law, and the corresponding proportion of particles can be measured based on density of the suspension.

##### 4.1.2.1 Validation of hydrometer method for struvite sedimentation

The hydrometer method is widely used in determination of soil particle granulometry, thanks to its simplicity and ready-to-use procedure. The hydrometer, a floating lenticular glass buoy with a scale attached to its top end,

is introduced into the suspension. The scale directly translates the buoyancy force – depending on the liquid's density – into grammes of solids contained in the liquid (with the deduction of the initial reading). In soil science, the hydrometer readings are recorded in specific intervals (corresponding to specified particle diameters of the soil fractions) up to 12 hours (Or et al., 2007).

For various struvite recovery processes, sedimentation plays a basic role. If sedimentation velocity and therefore particle size distribution can be assessed using a simple method, such as the hydrometer method, process efficiency can easily be monitored in a cost-effective way. Thus, an adoption of the hydrometer method for struvite particle sizing was attempted, using a 1 L glass cylinder and a conventional hydrometer. Struvite precipitation was induced by adding 10 mL of bittern (270 mg magnesium) to 1 L of stored urine. The hydrometer was introduced into the suspension after 10 minutes of continuous mixing using a magnetic stirrer.

#### 4.1.2.2 Validation of pipette method for struvite sedimentation

An alternative method is the pipette method, which resorts to direct TS measurements of a sample drawn from the suspension after a certain time at a certain depth. According to the United States Department for Agriculture (USDA) 'Soil Survey Laboratory Methods Manual' (Burt et al., 2004), 25 mL aliquots were drawn at 10 cm depth in predetermined time intervals using a volumetric pipette. The aliquots were dried at 105 °C during 24 hours prior to weighing them using an electronic scale ( $\pm 0.1$  mg).

Ten mL of bittern (270 mg magnesium) was added to a 1 L glass column filled with stored urine and the contents were mixed during 10 minutes using a magnetic stirrer. The sampling series started immediately after the stirrer had been switched off; samples were drawn at the follow-

ing intervals: 0, 2, 5, 10, 20, 30, 60, and 90 minutes. As struvite is affected by temperatures above 55 °C (Bhuiyan et al., 2008), the weight of three 1 mL liquid samples drawn using a Socorex piston-driven 1000  $\mu$ L pipette was also measured directly after the samples were taken, and the density was calculated.

To estimate the TS sedimented during the process, the initial TS concentration measured in the urine and the bittern (assuming perfect mixing) were deducted from the measured values after drying and weighing. As the precipitation and sedimentation process follows complex mechanisms, the absolute precipitated struvite cannot be calculated (as other minerals also precipitate and sediment during the process). Nonetheless, the experiment may produce some indications on the sedimentation time required in an up-scaled process. All the experiments were carried out at a room temperature of 20 °C.

### 4.1.3 Testing of the effects of flocculants on recovery efficiency and settling velocity

#### 4.1.3.1 Availability of flocculants in Nepal

In a perspective of general interest in flocculation for wastewater treatment in Nepal, the availability of various low-cost flocculants was assessed. A brief analysis of the potential use in struvite recovery will be presented in the results section.

As a reference, the performance of two commercial synthetic polyacrylamide (PAM) flocculants (Ensola 2001 and 2051) were compared to the locally available flocculants and lime as alternative precipitant. The Ensola flocculants are used in wastewater treatment in Switzerland (Ensola GmbH, Wetzikon, Switzerland). According to the producer, the product should be applied at a dose of 10 ppm (dilute for easier dosing prior to application).

**Table 5:** Flocculants and precipitants examined for their effect on struvite sedimentation velocity.

#	flocculant	description	preparation	test dose
A	alum	$\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$	grind to fine diameter, dissolve 1 g in 100 mL deionized water	500 mg·L <sup>-1</sup>
L	lime	$\text{Ca}(\text{OH})_2$	dissolve powder in deionized water	100 mg·L <sup>-1</sup>
E0	Ensola 2001	cationic polyamine	produce stock solution by diluting 1 mL in 100 mL deionized water	10 mg·L <sup>-1</sup>
E5	Ensola 2051	anionic polyamine	produce stock solution by diluting 1 mL in 100 mL deionized water	10 mg·L <sup>-1</sup>
M	moringa oleifera	dried seeds	dry seeds at room temperature, produce emulsion using a food blender with 5 g seeds and 200 mL tap water	500 mg·L <sup>-1</sup>

#### 4.1.3.2 Comparison of the effects of flocculants on sedimentation

In an experimental array identical to that of the determination of sedimentation velocity, the effect of various flocculants was tested in 1 L columns at the AEC laboratory at KU in Dhulikhel. Twenty-five mL aliquots were taken at 10 cm depth at intervals of 0, 10 minutes, 1 hour, and 1 day, and dried at 105°C for 24 hours prior to weighing, in order to determine the total solid (TS) content.

In a first experimental series, alum, lime, Ensola 2001, and Ensola 2051 were tested. Ten mL of bittern (270 mg of magnesium) were added to 1 L of stored urine and mixed continuously during 10 minutes using a magnetic stirrer. The flocculants were added after these 10 minutes and stirring, at a slower speed, continued for 2 minutes. In addition to the columns, where the flocculants were applied, a blank sample of urine with only bittern addition (without flocculant addition) was also examined using the pipette method.

In a second experimental series, the effect of dried and ground moringa oleifera seeds on flocculation was compared to a normal settling induced only by bittern addition (10 mL, i.e. 270 mL magnesium). TS and phosphate concentration (after acidification by 1 M HCl) were measured at the described interval. Additionally, ammonium concentration was compared between the initial suspension (after bittern addition and mixing) and the final supernatant after struvite settling. A column containing only stored urine without bittern addition, was also observed for its reaction to moringa seed application. The flocculants were prepared and dosed as described in Table 5.

The use of moringa oleifera seeds for water or wastewater treatment has been tested for COD (Bhuptawat et al., 2007) and turbidity removal (Katayon et al., 2006). The recommended dose ranges from 50 to 500 mg·L<sup>-1</sup> (dry weight of the seeds before processing). The removal of nutrients, such as nitrogen or phosphorus by addition of moringa oleifera seeds has not been tested yet.

#### 4.1.3.3 Comparison of the effects of flocculants on filtering efficiency

The above mentioned flocculants (except moringa oleifera seeds, which were not available at the time of the test) were also tested for their effect on filtering efficiency. In a cross test, the 4 columns of urine with bittern and the respective flocculant plus 1 column without flocculant addition were prepared and 100 mL of suspension were filtered on each of the five different filter materials tested as described previously: cotton fabric, nylon fabric, Nepali paper with a weight of 50 g·m<sup>-2</sup>, 70 g·m<sup>-2</sup>, and 110 g·m<sup>-2</sup>.

#### 4.1.4 Development of an improved struvite precipitation reactor

##### 4.1.4.1 Potential for improvement of the first reactor

The operation of the first pilot scale reactor tested in the field during the previous project phase (refer to project intermediate report: Etter, 2009) displayed a limited solid removal efficiency as well as some potential for improvements in the handling:

- A large portion of the precipitated struvite powder was found at the bottom of the cylindrical PP tank, as the particles passed through the gap between the filter tray and the reactor wall.
- The reactor operation required long time intervals of up to 12 hours for the sedimentation of the struvite.
- For the struvite harvesting, the entire stirring mechanism assembly had to be lifted up together with the sheet metal cover of the reactor.
- Frequently the filter tray was blocked inside the reactor and had to be pulled out by bending the reactor's plastic wall.
- The inexpensive plastic fittings (taps, adaptors etc.) broke easily and the sealing at the reactor-pipe interface proved to be a weak point prone to leakages.

##### 4.1.4.2 Improved sheet metal reactor with a tapered bottom

To avoid complications with the filter design, the second reactor was designed with a conically shaped bottom. Initially, the material of choice would have been PP or PE, given its insensitivity to corrosion. Nevertheless, the required plastic processing technologies (plastic bending and welding) were not accessible in Nepal. Alternatively, the reactor tank was assembled using galvanized steel sheet (22 gauge: 0.85 mm for galvanized steel), which can easily be found and crafted throughout the Kathmandu Valley and in most of the regions in Nepal. The joints were crimped, riveted, and sealed using common silicon sealant. For improved sealing, the socket of the bottom outlet was reinforced by soldering (Figure 13).

The pipes and fittings were selected from the new Nepa-top PP product line, which has significantly improved the durability of plastic appliances. The interface between the galvanized sheet metal tank outlet and the ball valve showed to be prone to leakage, as the cylindrical outlet carries a lateral seam, which produces a slight indent in its circular rim. The final version of the reactor was fitted with the adequate connection between the sheet metal part and the PP ball valve (Figure 14):



**Figure 13:** Detail on the reactor tank assembly: lower outlet reinforcement through soldering and crimped and riveted seam along the reactor side.



**Figure 14:** Detail view on the lower reactor outlet from the sheet metal tank to the PP ball valve

1. 1" metal cast iron bushing
2. 1" Nepatop adaptor from male thread to 1" PP pipe
3. short piece of 1" PP pipe
4. 1" Nepatop PP ball valve

The filter bag was directly attached to the ball valve using a string wound around the pipe. Initially a nylon fabric filter bag with approximately 1500 cm<sup>2</sup> filtering surface was used. Since filtering lasted more than 1 hour for high struvite loads, the filtering surface was increased to approximately 2000 cm<sup>2</sup> in a second cylindrical nylon fabric filter bag.

The stirring mechanism was constructed following a similar design as for the previous reactor, though the amount of metal used was reduced significantly in order to bring down production cost (1<sup>st</sup> reactor's stirring mechanism: 2800 NRs; 2<sup>nd</sup> reactor's stirring mechanism: 1300 NRs). Instead of a thick steel sheet covering the entire reactor opening, a cross-shaped support of 25 x 4 mm steel bars was laid across the reactor and covered with a plastic tarp. Two 50 x 150 mm steel stirrer blades were welded to the stirrer shaft (12 mm steel bar) and slightly twisted at the outside to obtain a propeller-like shape.

A reactor stand using 25 x 25 mm T-shaped steel bars was also manufactured to hold the reactor at sufficient height allowing for filtering and effluent drainage. Compared to the first reactor's stand, the second one's had to be raised to 1.2 m (see overall reactor view Figure 15).



**Figure 15:** Overall view of the improved pilot scale struvite recovery reactor (right), beside the first reactor (left).

## 4.2 Selection of magnesium sources

### 4.2.1 Comparison of availability and price of magnesium in Nepal

Potential magnesium sources for the struvite precipitation process were already evaluated during the first project phase. A brief overview on the concerned magnesium compounds is presented here:

- Magnesium sulphate ( $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ). Imported as fertilizer from India and tested in struvite precipitation in the first STUN reactor, achieving mean precipitation rates of 86 %. The fertilizer was imported as granulate by Rohit Chemical Traders P. Ltd. in Birganj and sent to Kathmandu by courier. There are no regular imports of magnesium sulphate at the moment, therefore the price was set a relatively expensive 40 NRs $\cdot\text{kg}^{-1}$ .
- Bittern (brine solution issued from salt production from seawater). For the first project phase, a 5 L brine sample was shipped from the salt production site in Kutch, State of Gujarat, near the Indo-Pakistani border to the UN-Habitat country office in New Delhi, from where it was transported by UN-Habitat staff as personal luggage on a flight to Kathmandu. Numerous contacted couriers in Kathmandu refused to ship chemicals or liquids across the border between India and Nepal. The first analysis of the bittern revealed a magnesium content of 2.62 %, and phosphorus removal rates of above 95 % were achieved by means of bittern addition to stored urine in the first reactor.
- Magnesite samples from the abandoned mine site in Kharidhunga, Dolakha District (80 km East of Kathmandu) had been taken, but the magnesium content had not been analyzed yet, nor had the rock been tested in pre-treatment for struvite precipitation (dissolution in strong acid).

#### 4.2.1.1 Evaluation of the potential of bittern use in collaboration with the salt producer

During the first research phase, frequent contacts with South Asia's largest salt producer (The Jakhau Salt Company, part of the Archean Group of Companies) were maintained. As the company had provided us the first brine sample, they followed the research closely and were interested in the further development of brine recycling.

In March 2009, I had a meeting with Mr. V.R. Venkataraman (Chief Executive Marine Chemicals of the Archean Group of Companies) in New Delhi to discuss the potential of bittern reuse in struvite production and to explore the possibilities of further processing of the brine, aiming at lower volumes and weight for the transport to Nepal. Refer to the results section for a detailed description of the bittern production and further effluent processing.

The salt production process was studied in a perspective of developing new treatment steps in nutrient recovery from urine, i.e. nitrogen concentration.

#### 4.2.1.2 Analysis of magnesite from the Dolakha mine site

Two different rock samples from within the abandoned mine premises (Figure 16) in the Dolakha District were taken and subsequently analyzed for their processing requirements, in order to estimate economical implications entailed by magnesite use for struvite precipitation in Nepal (consult section below for details on the lab analysis).

### 4.2.2 Comparison of magnesium content in compounds

#### 4.2.2.1 Magnesium sulphate analysis

A sample of the magnesium sulphate fertilizer powder was sent to the Eawag laboratory in Dübendorf, Switzerland for analysis on its magnesium and sulphate contents. After dissolution of the  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  powder in deionized water, the magnesium content was measured using ICP-OES, whereas sulphate was measured by means of IC.

#### 4.2.2.2 Bittern mineral content analysis

A sample of salt brine obtained from the Jakhau Salt Company was also shipped to the Eawag laboratory for analysis of its mineral content. Refer to the results chapter for information on the methods used for mineral analysis.

The Jakhau Salt Company provided a second sample with significantly higher magnesium concentration (estimated  $\text{MgCl}_2$  content: 40 % according to company data) to the UN-Habitat Country Office in New Delhi, from where it was intended to be transported to Kathmandu. However, the brine sample was confiscated at the Delhi International Airport by the Indian police, despite of an accompanying letter by UN-Habitat India. At present, no detailed data on the magnesium concentration of this concentrated brine are obtainable, although another sample for a closer analysis should be shipped to Nepal in the near future.

#### 4.2.2.3 Magnesite dissolution experiments and mineral analysis

The rock samples (Figure 16) taken at the abandoned mine site in the Dolakha District were first transported to the AEC laboratory at KU in Dhulikhel, Kavrepalanchok District. As the dissolution experiments using highly concentrated HCl showed to be ineffective, part of the sample was sent to the Eawag laboratory for further analysis.



**Figure 16:** The abandoned magnesite mine site in Kharidhunga in the Dolakha District.



**Figure 17:** Magnesite rock sample taken at the abandoned mine site in the Dolakha District.

The magnesite samples had to be dissolved using aqua regia digestion combined with microwave heating for mineral analysis according to an Eawag internal method (Moench, 2009). The digested samples were analyzed using ICP-OES. Refer to the results chapter for a list of the analyzed minerals.

### 4.2.3 Assessment of necessary magnesium source treatment prior to struvite precipitation

#### 4.2.3.1 Magnesite treatment for struvite precipitation

Based on the laboratory experiments conducted on magnesite dissolution and mineral content analysis, the possibilities for a potential treatment process of magnesite could be evaluated.

#### 4.2.3.2 Concentration of bittern to improve transportability

In the dialogue with the Jakhau Salt Company, the potential to ship highly concentrated  $MgCl_2$  brine to Nepal was assessed, in order to reduce transportation costs and energy. For future large-scale operations, this concentrated brine would certainly be the preferable magnesium source in the struvite production process. Nonetheless, the import into Nepal remains complicated at present.

### 4.3 Integration of pre- and post-process options of struvite production

To develop an user-friendly and viable process, which can easily be reproduced at a local level, the entire production chain from urine harvesting to the final struvite fertilizer product needs to be considered. Within the framework of this study, potential urine collection sites and production locations were evaluated for a large-scale process, to examine the feasibility of struvite production not only with a view on magnesium sources as input factor, but also with an emphasis on efficient urine collection.

On the output side, the post-process options to assure easy handling of struvite, i.e. to produce a granulated fertilizer product, were studied in a lab scale test.

#### 4.3.1 Assessment of potential urine harvesting sites

With regard to the future up-scaling of the STUN project, potential urine harvesting sites were inventoried. Through diverse contacts with local NGOs, public administrations etc. struvite production experience a sound interest and the willingness to collaborate with a future large scale operation.



**Figure 18:** Production of granules from medicinal powder as practiced in Tibetan medicine by means of a revolving steel drum (Shechen Clinic, Kathmandu).

#### 4.3.2 Granulation of struvite powder

Numerous solid fertilizers are marketed in the form of granules for easier dosage, and reduction of wind transport after application. Struvite usually forms lumps or a crust on the filter fabric, and decomposes partly into powder form, when removed from the filter.

To improve the handling of struvite and increase its marketability, a method for granulation of the struvite powder was sought.

In small scale and industrial processes revolving steel drums are used to form pellets (e.g. production of pills in Tibetan medicine, Figure 17) out of a powder with addition of small quantities of water, and, if required, an adhesive agent.

For tests on struvite powder, a small rotating drum was constructed using a steel pot (diameter 20 cm) and an electric fan motor (40W, 3 speed presets), as shown in Figure 18. A small quantity of struvite powder was introduced into the rotating drum (rotation speed approximately 60 rpm), and water was added gradually, until struvite granules of various diameters formed.



**Figure 19:** Experimental rotating steel drum for struvite granulation constructed from a fan motor and steel pot (20 cm diameter).

## 4.4 Laboratory analysis

All samples for ammonium and phosphate analysis were filtered by two filtering steps prior to analysis, to reduce interferences to a strict minimum:

- 0.7  $\mu\text{m}$  pore size paper filter (to prevent clogging of the 0.45  $\mu\text{m}$  filter, as recommended by Tilley, 2007).
- 0.45  $\mu\text{m}$  pore size membrane filter (as recommended sample treatment by Standard Methods, 2006).

### 4.4.1 Phosphate – molybdovanadate method

Phosphate was analyzed using the molybdovanadate method (HACH method # 8114) for reactive phosphorus with a single liquid molybdovanadate reagent (HACH). After filtering, samples were diluted 1:100 (for stored urine) or 1:10 (for the process effluent) down to the photo-spectrometer's measurements range from 0.1 to 16.6 mg  $\text{PO}_4\text{-P}\cdot\text{L}^{-1}$ .

Accuracy was checked by standard addition (1000 mg  $\text{PO}_4^{3-}\cdot\text{L}^{-1}$  Merck standard solution), and revealed a standard deviation of 9.7 mg  $\text{P}\cdot\text{L}^{-1}$  for a sample containing 277 mg  $\text{P}\cdot\text{L}^{-1}$  (comparable to the concentrations found in stored urine in Siddhipur).

This value, corresponds to a percentage of 3.5 %, is comparably low to the mean standard deviation cited in Standard Methods (2006) of 8.6 %. For lower concentrations (such as the STUN process effluent), the standard deviation will be greater).

To analyze particulate phosphorus (in struvite), the samples were acidified by 1 M HCl prior to filtering. A comparison with the initial phosphorus content proved that this acidification was sufficient to dissolve the precipitated struvite. pH only interferes with the colorimetric measurements induced by the molybdovanadate reagent at high levels (pH > 10) according to Standard Methods (2006). According to the HACH method manual, only 'extreme' pH values interfere with phosphorus measurements.

## 4.5 Outlook on the dissemination of struvite production

After the completion of the present research, the potential of struvite production shall be further explored in Nepal. To explore potential future collaborations, a coordination workshop was organized on 11 June 2009 with 40 participants from different NGOs, government offices, local administration etc. At this occasion, the research findings were presented, and the potential for future collaboration discussed.

### 4.4.2 Ammonium – salicylate method

All samples for ammonium analysis were diluted 1:10'000 with distilled water (as recommended by Tilley, 2007) to minimize interferences and to match the measurement range of 0.01 to 0.5 mg  $\text{N}\cdot\text{L}^{-1}$  (salicylate). Dilution was made in two steps by diluting 1 mL of the sample in 100 mL for each step. The HACH salicylate method (HACH method # 8155) based on powder pillows reagent was used, as it gives high precision results. Standard addition with a 1000 mg  $\text{NH}_4^+\cdot\text{L}^{-1}$  standard solution (Merck) was carried out for verification of the measurements' accuracy. The disadvantage of the salicylate method is its relatively high price (~ 2.50 € per sample)

### 4.4.3 pH

pH was measured using a WTW pH315i pH-meter calibrated before each series of measurements with pH = 4.01 and pH = 7.00 buffering solution (Merck). A SensoTix 31 electrode was used for the field and laboratory measurements. The electrode was rinsed with deionized water before and after every measurement.

### 4.4.4 Electric conductivity EC

EC was measured with a LF340 by WTW. The uncorrected EC and temperature (measured by the EC electrode) were reported separately. The measured EC was temperature compensated during data processing by the following formula:

$$(3) \quad EC' = EC / (1 + \alpha(T - T'))$$

$EC'$  compensated EC

$EC$  measured EC

$\alpha$  temperature correction coefficient  
(0.02 for water samples according to Standard Methods, 2006)

$T'$  reference temperature (25°C)

$T$  measured temperature

UN-Habitat plans to promulgate the technology by publishing a manual on struvite production in both English and Nepali. In addition, plans to produce a radio programme, and public presentations are being discussed. At present, the continuation of the STUN project has not been assured yet. Nonetheless, the technical and logistical support from various sides can be guaranteed and the project can count on a broad interest.

# 5

## Results and Discussion

*Increased process efficiency tested on the STUN pilot scale reactor in Siddhipur*

### 5.1 Optimization of liquid-solid separation

#### 5.1.1 Comparison of filter designs and materials

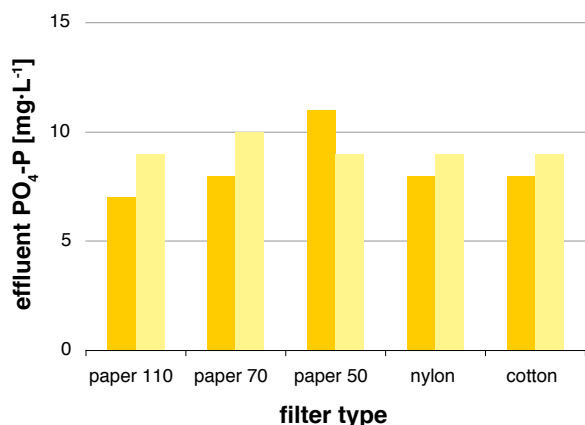
##### 5.1.1.1 Lab tests of filter materials

- 
- *Filtering efficiency similar in all tested materials (appr. 95%).*
- 
- *Recommended material should be resistant and durable (e.g. nylon or cotton fabric).*
- 

The five tested filter materials all showed similar removal rates. According to the phosphate measurements, removal rates can be expected at a range between 94 and 96 % (Figure 20).

If TS content was used as an indicator for filtering efficiency, the five different filter materials repeatedly display similar performances (Figure 21). However, the solids retained by the filter surpass the projected struvite mass calculated based on the initial phosphorus content in the urine. It is to be assumed that other solids contained in the urine were also retained by the filter. Although this result does not allow one to draw a conclusion about the effective struvite removal, it indicates that the filter materials have similar properties compared to one another. The first series shows a peak value in TS retention for the cotton filter, which is probably due to a measurement error.

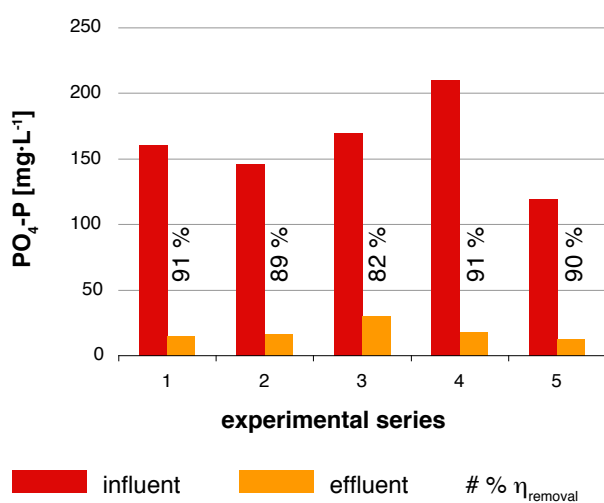
To express the effective struvite removal efficiency by filtering, the comparison of phosphate concentration is probably the most reliable indicator, as it focuses on the main substance of interest. TS is influenced by the initial composition of the urine, as well as by the solids contained in the precipitant (further minerals from the added bittern might also have precipitated).



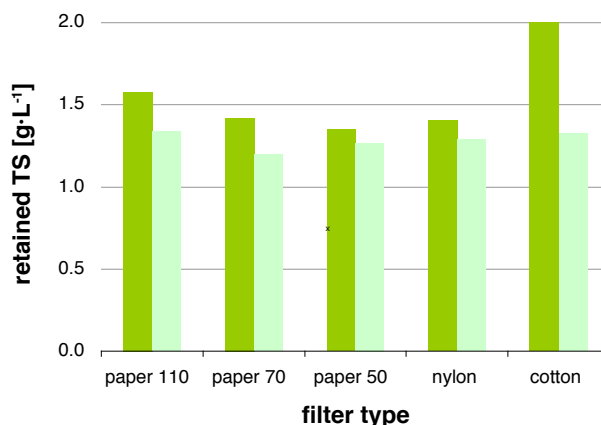
**Figure 20:** Two series of filtering efficiency as assessed at lab scale using effluent  $PO_4^{3-}$  as indicator. Initial concentration in the stored urine:  $170 \text{ mg}\cdot\text{L}^{-1} PO_4\text{-P}$ .

In addition, struvite will not remain stable when heated. Mass loss will start at  $55 \text{ }^\circ\text{C}$  (Bhuiyan et al., 2008), due to ammonium volatilization and water loss. For an absolute mass balance, the obtained results are thus not suitable, though they allow a comparison of the filter materials, if all the samples are treated equally.

Although this filter comparison at laboratory scale produces comparable results for the chosen set-up, the removal rates may not correspond to an experimental set-up at pilot scale. Given the complex filtering kinetics; the filter cake is assumed to play a more important role than the filtering tissue itself. Therefore, the filter efficiency of a selected filter material has to be assessed in field conditions also, to verify its suitability for an efficient process.



**Figure 22:**  $PO_4^{3-}$  removal rates for 5 different experimental series on the pilot scale struvite precipitation reactor. Series 1 to 3 used a smaller filter bag (surface:  $1500 \text{ cm}^2$ ), series 4 and 5 a larger improved version (surface:  $2000 \text{ cm}^2$ ).



**Figure 21:** Two series of filtering efficiency as assessed at lab scale using TS removal (TS in suspension - TS in filtrate) as indicator. Projected struvite mass at maximum precipitation efficiency was  $1.21 \text{ g}\cdot\text{L}^{-1}$ .

The tests on filter materials confirmed that the selection of the most adequate filter material can be based on other factors than the filtering efficiency. In a scaled up process, the resistance and the longevity of the material will be more crucial for a regular operation.

Therefore, paper should not be employed, as it is easily torn by mechanical influences. Ideally, a filter bag can be reused many times, thus it has to withstand repeated removal of powder adhering to its surface. Widely available cotton or nylon filter fabrics are projected to be equally suitable for a process at larger scale.

#### 5.1.1.2 Field tests on filter designs

- Struvite removal efficiency constant at about 90 %.
- Nylon filter bags performed well in the every day reactor operation.

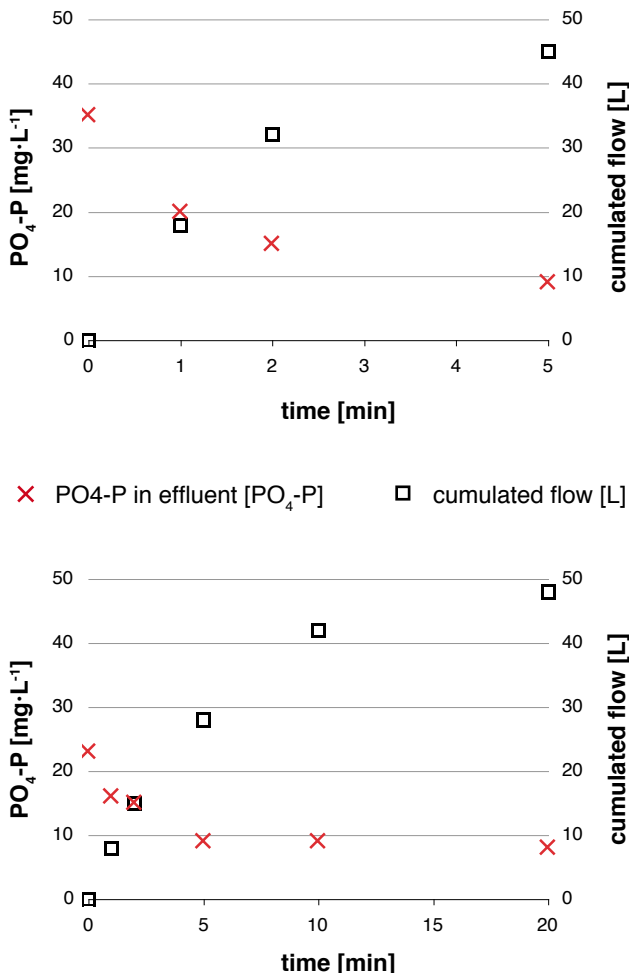
In the field tests, the filter efficiency assessed on the basis of phosphate concentration showed rather uniform results ranging from 89 to 91 % (Figure 22). During series 3, a leakage was detected at the connection between the filter bag and the reactor outlet, which explains the lower phosphate removal rate of 82 %. No difference was observed between the smaller filter bag (surface:  $1500 \text{ cm}^2$ ) used in series 1 to 3, and the larger version (surface:  $2000 \text{ cm}^2$ ) used in series 4 and 5.

Whereas for experimental series 1, 2 and 3, the effluent sample was taken from the effluent collection tank after filtration and analyzed for its phosphate content, for experimental series 4 and 5 the phosphate concentration in the effluent was integrated based on 4, respectively 6 measurements at set time intervals during filtration. Despite the differing measurement methods, the results proved to be comparable.

### 5.1.1.3 Field tests on filter cake buildup

- Effluent phosphate concentration decreases gradually with filter cake buildup.
- Integrated concentration over time corresponds to concentration in mixed sample.

If the effluent phosphate concentration is measured at set intervals, a gradual decrease can be observed, due to the filter cake buildup, which increases the removal efficiency (Figure 23). This phenomenon may also explain the steady removal rate despite varying influent phosphate concentrations. The first run (left) started from a relatively high initial concentration of  $210 \text{ mg}\cdot\text{L}^{-1} \text{ PO}_4\text{-P}$ ; consequently the effluent 'first flush' concentration rose up to  $35 \text{ mg}\cdot\text{L}^{-1} \text{ PO}_4\text{-P}$ . In the case of the second run,  $119 \text{ mg}\cdot\text{L}^{-1} \text{ PO}_4\text{-P}$  initial concentration lead to  $23 \text{ mg}\cdot\text{L}^{-1} \text{ PO}_4\text{-P}$  'first flush' concentration measured in the effluent. However, the overall filter efficiency (calculated by integration of



**Figure 23:** Effluent  $\text{PO}_4^{3-}$  concentration as a function of time from the opening of the reactor's main outlet. The decrease in phosphate concentration accompanies the gradual buildup of the filter cake. The overall integrated filter efficiency reaches approximately 90 %.

the flushed phosphate mass over time) presented results comparable to the measurements of mixed samples of the effluent collection tank (see previous paragraph).

Compared to existing struvite recovery installations, the removal rate of approximately 90 % is a good result. Yet, there are few publications that contain data on a similar set-up operating with filter bags. In the literature on laboratory scale experiments, the liquid-solid separation method is often not disclosed.

Although it has to be presumed that in the majority of the cases, filtering is involved, and the methods might not be directly applicable at pilot scale, as in the STUN field tests. At a large scale, liquid-solid separation in struvite recovery frequently resorts to sedimentation. Although the technology can only be compared to existing installation with certain restraints, the achieved overall removal rate represents certainly an asset for the STUN process.

## 5.1.2 Examination of granulometric distribution and sedimentation velocity of struvite

### 5.1.2.1 Validation of hydrometer method for struvite sedimentation

- Hydrometer method not suitable for struvite sedimentation measurements.

The hydrometer method is not suitable for measurements on struvite sedimentation due to two principal factors:

- After mixing the urine and the magnesium source, some foam may form at the surface of the suspension. Hence, the precise reading of the hydrometer is not possible, in particular during the first minutes of the sedimentation period.
- The solid content in urine after struvite precipitation is too low. For urine containing  $250 \text{ mg}\cdot\text{L}^{-1} \text{ PO}_4\text{-P}$ , the maximum precipitated struvite mass will attain just  $2 \text{ g}\cdot\text{L}^{-1}$ , whereas a hydrometer's scale features  $1 \text{ g}\cdot\text{L}^{-1}$  divisions, thereby allowing readings barely below the total quantity to measure.

### 5.1.2.2 Validation of pipette method for struvite sedimentation

- The pipette method gives valuable indications on struvite sedimentation.
- In lab conditions at  $20^\circ\text{C}$  ambient temperature: struvite settles at  $1 \text{ cm}\cdot\text{min}^{-1}$ .

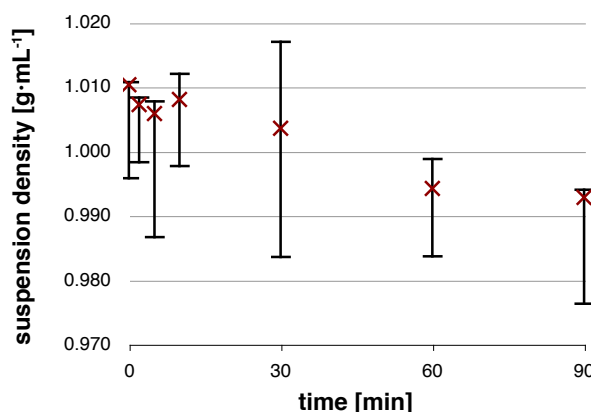
Compared to the hydrometer method, the pipette method allowed a more precise conclusion on the sedimentation behaviour of struvite in urine. The first measurements ser-

ies recorded the weight of three 1 mL samples drawn using a Socorex 1000  $\mu\text{L}$  piston-driven pipette in the described intervals. A previous pipette calibration had revealed a standard deviation of  $\pm 0.0021$  g for the 1 mL preset (on 10 deionized water samples). However, the mean standard deviation from measuring three urine/struvite suspension samples at each time interval rose up to  $\pm 0.0096$  g. This increased deviation shows the heterogeneous distribution of the struvite in suspension. In addition, the dynamics at the pipette tip during the liquid intake might cause a varying concentration of struvite crystals in the sample.

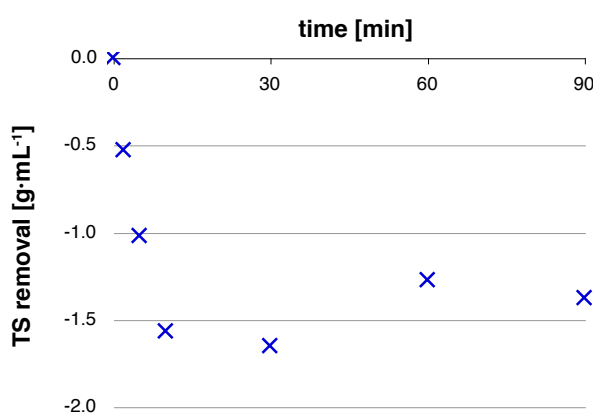
As during sedimentation the density changes only from 1.01 to 0.99  $\text{g}\cdot\text{mL}^{-1}$ , the error in density measurements is relatively high. A decreasing trend in the median density during sedimentation can be observed (Figure 24), though the experiment did not deliver absolute values, which could be used in sedimentation velocity calculations. The method adopted from soil science (Burt et al., 2004) displayed more precise results. As described in the methodology chapter, TS content of the aliquots – drawn using a Borosil 25 mL glass volumetric pipette with a rubber filler – was measured. From the TS content measured in the samples drawn at the selected intervals, the initial TS content in urine and bittern was deduced.

The time series showed that the minimum TS content at 10 cm depth in the column was already attained after 10 min settling time at 20 °C (Figure 25). The maximum decrease in TS content was recorded at 1.65  $\text{g}\cdot\text{L}^{-1}$ , i.e. 83 % of the struvite potentially formed struvite mass (2  $\text{g}\cdot\text{L}^{-1}$  for a  $\text{PO}_4\text{-P}$  concentration of 260  $\text{mg}\cdot\text{L}^{-1}$ ), not considering ammonium and water loss induced by heating. As mentioned for the previous experiments, the absolute mass of the solids cannot be compared, given the instability of struvite above a certain temperature. In this case, the measured TS content in the supernatant is higher than expected, as it does not drop below the initial value of urine and bittern (in a perfectly mixed setting).

In general, measurements on struvite sedimentation behaviour have to be interpreted and applied with great caution. Continuous aggregation and disaggregation of particles will cause an inaccurate size distribution analysis. In soil science, chemical, mechanical or ultrasonic methods are used to cause dispersion of the particles prior to sedimentation (Burt et al., 2004). However, for the purpose of struvite sedimentation, these aids are not appropriate, as they would affect the process as a whole. The pipette tests revealed that struvite sedimentation under the given circumstances, is relatively quick ( $1\text{ cm}\cdot\text{min}^{-1}$ ). In the field, these figures would probably have to be revised, especially during the cold winter season. As viscosity is difficult to estimate and varies greatly in urine, a simple analytical conversion of the data obtained at lab scale is not possible. During the first field test phase of the STUN project, extremely long sedimentation times ( $> 12$  hours) were recorded for the pilot scale reactor (40 cm depth).



**Figure 24:** Decrease in median density of the urine/struvite suspension versus time. The error bars indicate the lower and upper measurement values ( $n=3$ ).



**Figure 25:** Decrease in TS from initial suspension (urine & bittern) content versus time.

As mentioned, these are probably in part due to the low temperatures (5 °C during the winter season), but might also be attributable to a different crystal formation in the field setting.

### 5.1.3 Testing of the effects of flocculants on recovery efficiency and settling velocity

#### 5.1.3.1 Availability of flocculants and coagulants in Nepal

- Alum or lime for use as flocculants are easily available in Nepal.
- *Moringa oleifera* seeds can be found; their cultivation and use can be further promoted if necessary.

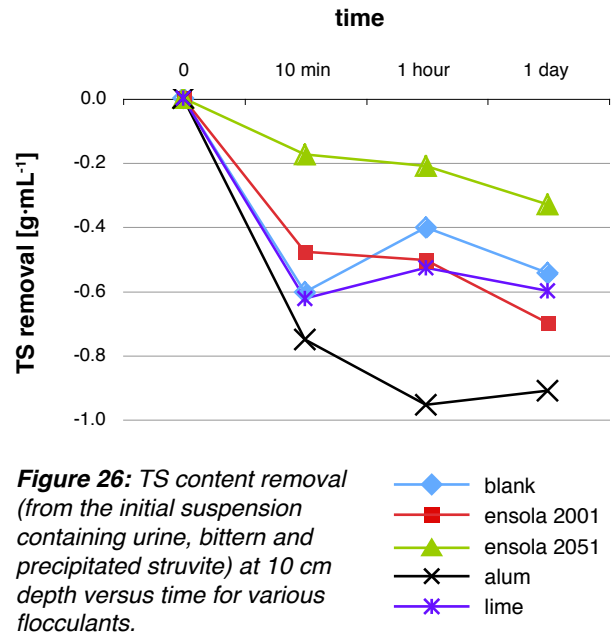
Despite of an extended search, chitosan was not found to be available in Nepal at the time of the present study. Alum ( $\text{Al}_2(\text{SO}_4)_3\cdot 18\text{H}_2\text{O}$ ), called फुटगिरी (phutgiri) in Nepali, can be found on any market in Nepal (50 NRs $\cdot\text{kg}^{-1}$ ), as it is widely used for its anti-bacterial properties in barber-shops. Aluminium toxicity affects numerous crops, the use

of alum thus has to be restricted to areas, where Al can be applied in agriculture without compromising plant growth (e.g. tea plants require aluminium as nutrient). Construction lime ( $\text{Ca}(\text{OH})_2$ ), called चूना (chūn) in Nepali, is widely available in the construction business. The moringa oleifera tree grows in the Tarai (southern lowlands of Nepal), where its fruits also play an important role in the local diet. In Kathmandu, the fruit may be sporadically found on markets at a price around 50 NRs·kg<sup>-1</sup>. In Nepali, the fruit is referred to as सजिवन (sajivan), although the same word is sometimes employed to relate to *jatropha curcas*, a plant cultivated for the production of biodiesel. Dried and packaged moringa oleifera seeds can be purchased in India (Chariar, 2009), where the knowledge on the beneficial properties has been spread to a larger extent. If larger quantities of moringa oleifera seeds are required in Nepal, a project in collaboration with local farmer associations could be launched.

### 5.1.3.2 Comparison of the effects of flocculants on sedimentation

- *Struvite sedimentation is only affected by alum or cationic synthetic flocculant.*
- *Moringa seeds cause a colour change in urine, though no effects on phosphate concentration.*

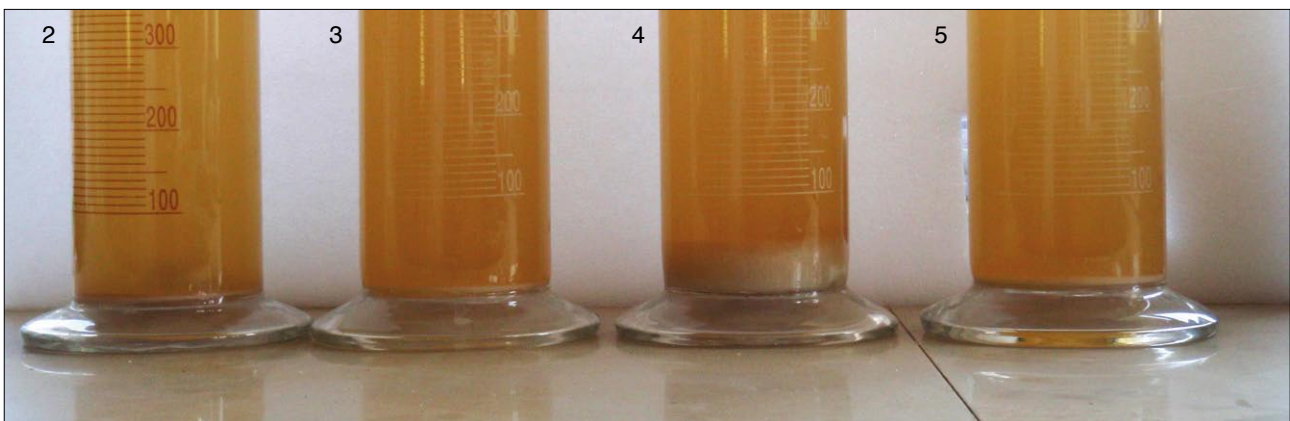
The tested flocculants showed varying effects on the TS content in the sedimentation columns. Interestingly, TS content increased at the beginning through the addition of the flocculants and precipitants (alum and lime as powder dissolved in deionized water; Ensola commercial flocculants as liquid diluted in deionized water). After a 10 minute sedimentation period, only alum had achieved a higher sedimentation rate than the blank sample. The lime showed to be indifferent compared to the blank sample. Initially, the cationic flocculant (Ensola 2001) did not produce any changes in sedimentation, whereas the anionic flocculant (Ensola 2051) even slowed down solids removal (Figure 26).



**Figure 26:** TS content removal (from the initial suspension containing urine, bittern and precipitated struvite) at 10 cm depth versus time for various flocculants.

After 1 hour, and equally after 1 day sedimentation time, all the absolute TS contents reached a comparable level. In terms of relative removal from the initial to the final content, alum achieved the best results, followed by the cationic flocculant (Ensola 2001). The column, where alum was applied, showed a 2 cm thick layer of sludge containing big flocks at the bottom after sedimentation. Similarly, the flocks in the column with Ensola 2001, were bigger than the flocks observed in the other columns, although they did not reach the size of the flocks caused by alum (Figure 27).

Szögi et al. (2006) compared the effect of anionic and cationic polyacrylamide (PAM) flocculants on phosphorus removal by filter bags after precipitation using lime ( $\text{Ca}(\text{OH})_2$ ). They observed that only the anionic flocculant was active on the formed compounds (chiefly calcium phosphates). In the case of struvite, the cationic PAM flocculant might have been effective to some extent (compared to no effect caused by the anionic PAM flocculant),



**Figure 27:** Sedimentation columns to test the effect of flocculants on struvite sedimentation. 1. blank (not visible), 2. Ensola 2001, 3. Ensola 2051, 4. alum, 5. lime. Flocculation can be observed in column 4 and to some extent in 2.

as struvite particles have a strong negative surface charge (Le Corre et al., 2007). Lime is probably not effective in stored urine at the applied dose due to the high alkalinity. High bicarbonate concentration in urine will rather lead to  $\text{CaCO}_3$  formation. In wastewater treatment, lime dosage for coagulation is calculated depending on alkalinity, not phosphorus content (Metcalf & Eddy, 2003).

The addition of dried and ground moringa oleifera seeds did not have any effect on struvite sedimentation or phosphate concentration in the suspension (Figure 28 top). TS content was slightly reduced at a dosage of  $500 \text{ mg}\cdot\text{L}^{-1}$  moringa seeds, though not to an extent comparable to struvite precipitation (Figure 28 bottom). A colour change in the urine treated with moringa seeds was observed (Figure 29), though its exact cause remains unknown. The absence of an effect of moringa on struvite sedimentation is not surprising, as the flocculating agent contained in the seeds is known to remove organic, but not mineral pollution from water (Lohri, 2009). The colour change caused by the natural flocculant may accordingly be explained through a flocculation of organic compounds.

### 5.1.3.3 Comparison of the effects of flocculants on filtering efficiency

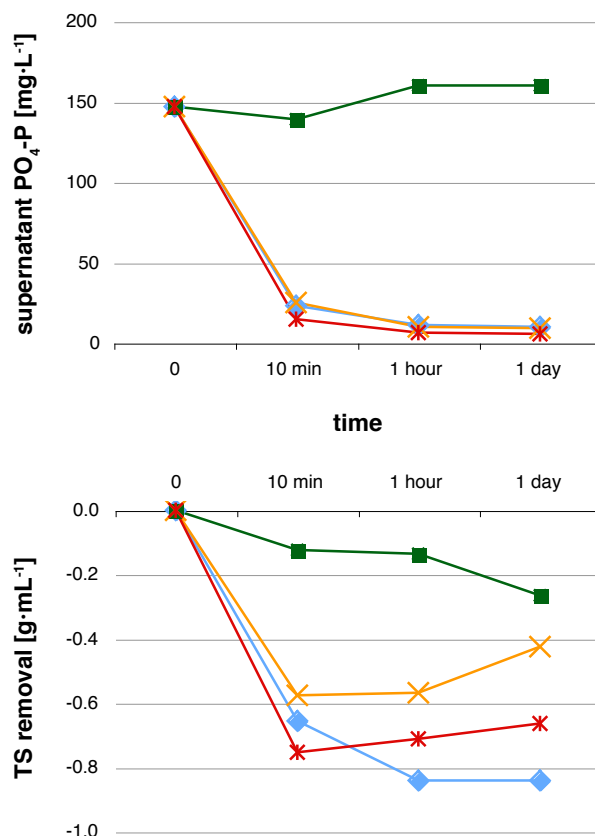
- Filtering efficiency was not significantly affected by flocculant addition.
- The use of flocculants is not suitable for struvite production in the given context.

No significant effects of flocculants on filtering efficiency were observed (Figure 30). For all combinations the effluent  $\text{PO}_4\text{-P}$  concentration is between  $6$  and  $12 \text{ mg}\cdot\text{L}^{-1}$ , i.e. a phosphate removal efficiency of 93 to 96 % on an initial content of  $170 \text{ mg}\cdot\text{L}^{-1}$ .

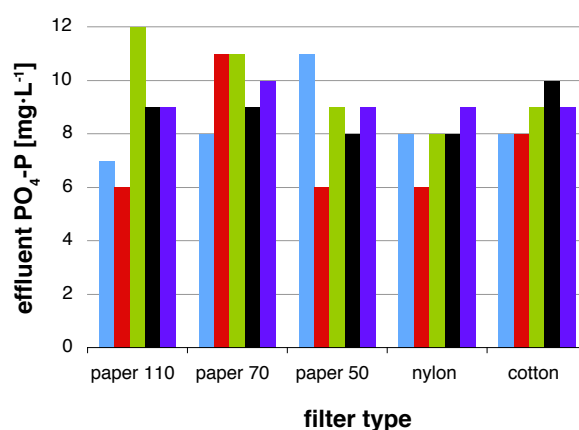
As no flocculants showed to improve struvite recovery significantly at laboratory scale, no experiments on flocculant addition on the pilot scale reactor were carried out.



**Figure 29:** Urine after struvite precipitation without (left) and with moringa oleifera seeds addition (right column).



**Figure 28:**  $\text{PO}_4\text{-P}$  concentration (top) and TS removal (bottom) versus time after addition of moringa seeds to urine treated with bittern.



**Figure 30:** Struvite precipitation effluent  $\text{PO}_4\text{-P}$  concentration as a function of filter type and flocculant application.

### 5.1.4 Development of an improved struvite precipitation reactor

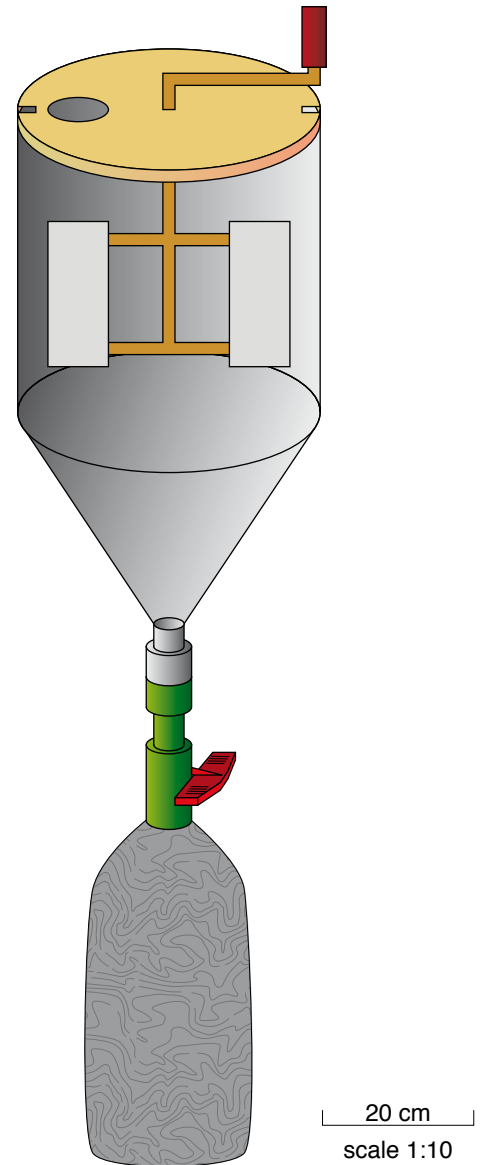
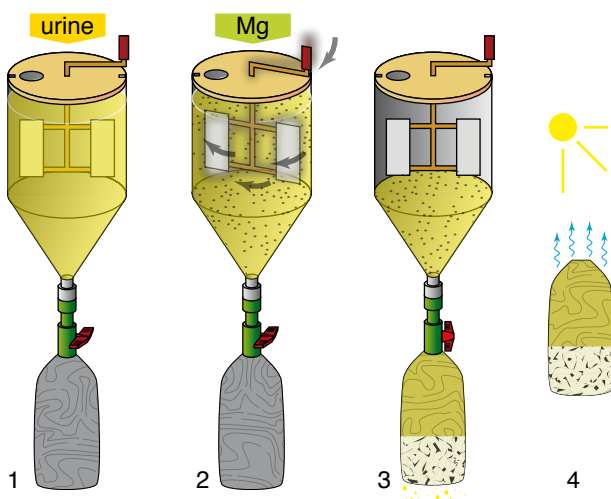
#### 5.1.4.1 Improved sheet metal reactor with a tapered bottom

- The improved reactor performed satisfactorily in the field.
- Small modifications need to be made to bring the process to a larger scale.

The second reactor was tested in the field during approximately one month. At the beginning of the test phase, some leakages at the lower reactor outlet had to be fixed. Especially the interface between the sheet metal outlet and the metal bushing was prone to leakage and had to be sealed with sufficient quantities of silicon seal tape. At a larger scale, it would be recommendable to solder a metal bushing directly to the sheet metal. Frequent handling of the outlet tap and the filter bag causes the outlet pipe to move slightly, and therefore to cause repeated leakage over long operation periods.

At large scale, the following points should be considered:

- Connection of the outlet tap to the lower reactor outlet has to be sturdy enough to withstand frequent valve operation.
- The filter bag should be attached to the outlet using a metal brace rather than just a string, to simplify the handling.
- The design of an entire filter module could be an option to further improve filter exchange and drying. The module would be changed as a whole after the filtering process and left to dry for the necessary period.
- The influent storage tank should be located above and effluent storage sufficiently below the reactor for a gravity-driven liquid flow, to avoid pumping.



20 cm  
scale 1:10

**Figure 31:** Schematic drawing of the improved reactor version with a tapered bottom.

**Top:** Overall view of the reactor.

**Left:** Process steps:

1. Fill the reactor with urine
2. Add magnesium and stir for 10 minutes
3. Open the lower outlet valve, let the suspension drain through the filter bag
4. Remove the filter bag, dry it, until the struvite can be removed in powder form

## 5.2 Selection of magnesium sources

### 5.2.1 Comparison of availability and price of magnesium in Nepal

#### 5.2.1.1 Evaluation of the potential of bittern use in collaboration with the salt producer

- Highly concentrated  $MgCl_2$  solution can be obtained from India.
- Two waste products – urine and bittern – can create new value through struvite production.

The understanding of the production chain leading from seawater to the manufacturing of salt is an important element in evaluating bittern or additional products for their potential use in struvite production. In the following paragraphs, a brief overview of the sea salt production process is presented (Venkataraman, 2009):

Raw seawater is pumped into an evaporation basin. As soon as salinity reaches a certain value through evaporation, the water is transferred to a subsequent basin, leaving behind the first precipitate. By increasing the salinity step by step, in one basin after another, the process is thus able to separate a sequence of salts (Figure 32). Salinity is expressed as degrees Baumé (°Bé), refer to box for details.

#### Degree Baumé

In salt production from seawater, salinity is expressed in degrees Baumé (°Bé), using a hydrometer for simple density measurements.

$$\rho = 145 / (145 - \text{°Bé})$$

(at 20 °C)

By the time the brine flows out of the last pond, the  $MgCl_2$  concentration has increased to about 40 %. The first bittern sample, which the Jakhau Salt Company provided to the STUN project, consisted of the effluent after NaCl precipitation (at 24-25 °Bé ~ density of 1200 kg·m<sup>-3</sup>).

The company has developed a process to harvest potassium; the production plant is under construction. Within 2 years it will be selling the harvested potassium to the governmental Indian fertilizer company IFFCO. After Potassium harvesting, the remaining effluent contains predominantly  $Mg^{2+}$  and  $Cl^-$ . Struvite production would therefore be an advantageous complementary process, creating new value through the combination of two waste products.

The production site in Kutch, Gujarat, Western India has a particular advantage in producing salt: the setting of an inverse estuary creates naturally high salt concentrations (Vethamony et al., 2007), as evaporation exceeds precipitation in India's most arid region. Abundant salt deposits have formed over time and salt mining has been known in the region for thousands of years. The seawater, which comes into contact with the sediments before reaching the intake of the salt production plant, has already an increased salinity, just below the precipitation threshold for NaCl ( $FeCO_3$  and  $CaSO_4$  precipitate before reaching the coast).

Visiting the salt production site is currently impossible for foreigners due to political reasons, given the plant's proximity (30 km) to the Indo-Pakistani border. The Jakhau Salt Company delivered a second sample of highly concentrated salt brine to the UN-Habitat country office in New Delhi. Unfortunately, the sample was confiscated by the Indian police at the Delhi International Airport, while en route for Kathmandu.

As the mineral recovery from seawater is entirely founded on evaporation, the process cannot be adapted to nutrient recovery from urine. The main obstacle to a more complete nutrient recovery from urine remains ammonium evaporation at low temperatures, thus nutrient loss and eutrophication by atmospherical transport.

#### 5.2.1.2 Analysis of magnesite from the Dolakha mine site

The magnesite mines at Khariðhunga in the Dolakha District were shut down in 1990. According to different sources the reasons for the closure range from excessive dust emission from the treatment plant near the Sunkoshi River, to technical problems experienced in the processing, to political issues. The extraction and transportation machinery is still on the site, although it would require a considerable investment to convert the mine back into operable conditions. Prior to closure of the Khariðhunga magnesite mine, 50'000 metric tonnes of dead-burned magnesite (MgO) were produced per year (Wu, 1994) in the processing plant in Lamosanghu, Sindhupalchok District. Near the magnesite deposits, a talc mine and a talc processing plant are still operated at present by the same company, which used to extract magnesite from Khariðhunga.

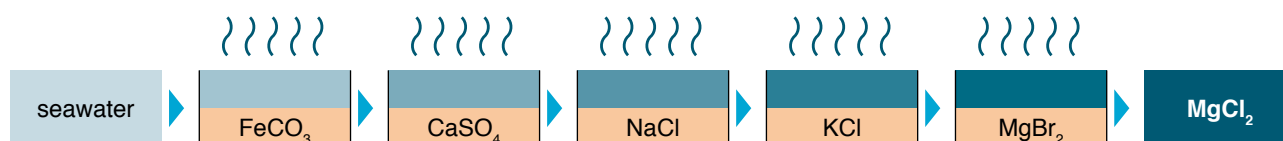


Figure 32: Precipitates from seawater in subsequent evaporation ponds in order of increasing salinity.

## 5.2.2 Comparison of magnesium content in compounds

### 5.2.2.1 Magnesium sulphate analysis

- Magnesium sulphate is of inferior quality (5 % Mg).
- Contamination has to be suspected in the fertilizer.

As suspected during the first experimental series on the pilot scale reactor, the measured Mg content (Table 6) in the magnesium sulphate powder was significantly inferior (5 %) to the potential value based on stoichiometric calculations (9.9 %). No further analyses were conducted, though for an application at large scale, a broad mineral analysis would be required, in order to ensure compliance with standards, as to prevent any negative impacts on crops by application of struvite or effluent.

### 5.2.2.2 Bittern mineral content analysis

- Brine after NaCl precipitation contains 27 mg·L<sup>-1</sup> Mg.
- Magnesium content can be further increased to 10 % by subsequent evaporation.

The brine sample provided by the Jakhau Salt Company in November 2008 showed an already elevated Mg content of 2.75 mg·L<sup>-1</sup> in the solution. For the complete mineral analysis refer to Table 7. According to the Jakhau Salt company, further concentration of the salt brine after NaCl precipitation through evaporation will lead to subsequent precipitation of KCl and MgBr (in relatively small proportions). A final concentration of an estimated 40 % MgCl<sub>2</sub> will be achieved, which would imply a 10 % Mg concentration in the brine (Mg being 25.5 % of mass of MgCl<sub>2</sub>).

The Jakhau Salt Company provided a second sample with high Mg concentration to the UN-Habitat Country Office in New Delhi, from where it was intended to be trans-

ported to Kathmandu. However, the brine sample was confiscated at the Delhi International Airport by the Indian police, despite of an accompanying letter by UN-Habitat India. At present, There is no detailed data on the Mg concentration of this concentrated brine, although it is hoped that another sample for closer analysis will be obtained in the near future.

Bittern can be considered as the most suitable magnesium source for struvite precipitation. If the Mg concentration in the solution attains 10 %, it will be equal to pure MgSO<sub>4</sub>·7H<sub>2</sub>O, which is in powder form and needs to be dissolved for an efficient precipitation process. Given that the magnesium sulphate is unlikely to be available in pure form, as the mineral analysis revealed, the bittern features another advantage when it comes to transport weight and volume in relation to effective magnesium content.

### 5.2.2.3 Magnesite dissolution experiments and mineral analysis

- Low magnesium content (16.6%) measured in samples.
- Higher grade magnesite ore deposits have been known in the region.

The analyzed magnesite samples (Table 8) contained considerably less magnesium (average 16.6 %) than pure CaCO<sub>3</sub> would contain based on stoichiometric cal-

**Table 6:** Mineral content in a dissolved MgSO<sub>4</sub>·7H<sub>2</sub>O:

Parameter	Mg <sup>2+</sup>	SO <sub>4</sub> <sup>2-</sup>
Unit	%	%
Method	ICP	IC
Value	5	20

**Table 7:** Mineral content measured from a bittern sample (after NaCl precipitation).

Parameter	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	TS
Unit	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>
Method	IC	IC	ICP	ICP	ICP	ICP	
Value	17'380	3'280	27'524	223	9'848	70'861	129'115

**Table 8:** Mineral content in two magnesite samples from the Kharidhunga mine site (Dolakha District).

Parameter	Ca <sup>2+</sup>	Na <sup>2+</sup>	Mg <sup>2+</sup>	Al <sup>3+</sup>	Si <sup>4+</sup>	K <sup>+</sup>	Fe <sup>3+</sup>	PO <sub>4</sub> <sup>3-</sup>
Unit	mg·g <sup>-1</sup>	mg·g <sup>-1</sup>	mg·g <sup>-1</sup>	mg·g <sup>-1</sup>	mg·g <sup>-1</sup>	mg·g <sup>-1</sup>	mg·g <sup>-1</sup>	mg·L <sup>-1</sup>
Sample I	2.01	0.05	164	0.35	detected*	0.03	7.05	0.40
Sample II	1.91	0.06	167	0.37	detected*	0.04	7.05	0.37

\* Silicon was detected, though the measurement unit had not been calibrated

culations (28.8 %). Near the magnesite mine site, talc ( $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$ ) deposits are also found and are currently exploited at a small scale. Although the Si content was not determined in the magnesite sample, it can be assumed to be relatively high, considering that Si is naturally abundant in the region and that dissolution of the magnesite required a complex procedure (aqua regia digestion and microwave).

According to Wu (1994), the magnesite deposits in Kharidhunga contain 88 to 96 % of magnesium oxide (MgO). The deposits contain an estimated 66 megatonnes (Mt) refractory-grade magnesite. Out of these 66 Mt, 25 Mt are high-grade recoverable reserves.

### 5.2.3 Assessment of necessary magnesium source treatment prior to struvite precipitation

#### 5.2.3.1 Magnesite treatment for struvite precipitation

Dissolution of the sample taken from the Kharidhunga mine site required aqua-regia digestion combined with microwave heating. In addition, the measured Mg content (16.6 %) was relatively low. However, literature sources cite high Mg contents and abundant reserves for the

Kharidhunga deposits (Wu, 1994). According to the mine operator, 50'000 t of dead-burned magnesite were produced annually prior to closure of the mine.

A detailed evaluation of the potential for magnesite processing from Kharidhunga deposits cannot be concluded within the framework of this study. At present, the mine and its extracting and processing installation are not in operation, hence no locally produced magnesium is available for struvite precipitation.

Nevertheless, as the political situation stabilizes, and demand for mineral resources increases, the mine may reopen in the future. Corresponding plans were announced by governmental sources, although frequent political changes might delay the implementation.

#### 5.2.3.2 Concentration of bittern to improve transportability

As described in the previous section, bittern can be further concentrated by subsequent evaporation after NaCl precipitation, attaining Mg concentrations of an estimated 10 % in solution. For future large-scale operations, this concentrated brine would certainly be the preferable magnesium source in the struvite production process. Nonetheless, the import into Nepal remains complicated at present.

## 5.3 Integration of pre- and post-process options of struvite production

### 5.3.1 Assessment of potential urine harvesting sites

- 
- *Urine is already being collected in larger volumes in Nepal.*
- 
- *Strong interest in the STUN project from various sides.*
- 

As struvite production is a new technology in Nepal, the STUN project experienced a high interest from various sides ranging from NGOs to public administrations to interested individuals. The researchers approached a number of times by organizations, which were interested in purchasing a struvite reactor for varying purposes. Among these requests, some have certainly a great potential for a future up-scaled version of struvite production:

- The Kathmandu Metropolitan City (KMC) constructed a new public toilet prototype equipped with urine diverting toilets and urinals. The toilets are fitted on a

trailer or truck and located near the great thoroughfares in Kathmandu. The faeces and urine tanks are emptied at a daily interval and transported to a central collection site. At present, 500 to 600 L of source-separated urine are collected daily from one toilet trailer. The KMC plans to install 30 such toilets by the end of 2009 (Upreti, 2009). Currently, the urine is discharged, due to lack of treatment facilities.

- At the Manakamana cable car 500-1000 L of urine is collected daily from the urinals in the cable car station. Shree Manakamana Mandir is one of the most important Hindu temples, and has been made accessible to a large public by Nepal's first cable car a few years back. It experiences an enormous influence from thousands of pilgrims every day and an extensive hotel infrastructure has been built up around the cable car stations. The potential for an extended urine collection system in this densely constructed area is being evaluated (Pokharel, 2009).

### 5.3.2 Granulation of struvite powder

- Granulation is feasible with low-cost equipment.
- An user-friendly fertilizer granulate can be produced from struvite.

The rotating drum showed to be an effective means to produce granules from struvite powder. Only water had to be added for the powder to adhere and form granules (Figure 33). Subsequently, the produced granules were air-dried during 24h to reduce their moisture content and increase stability (Figure 34). Granule diameters of up to 5 mm were achieved in the laboratory scale rotating drum. The granules could be separated through sieving; low diameter granules could be recycled into the process to produce a more uniform final granule size distribution.

In industrial production, steam is frequently used as binding agent (Venkataraman, 2009), which implies an increased energy demand. For struvite granulation in a rotating drum, only the considerably low energy input for the drum motor is required. In the test, the 40W motor proved to be relatively weak, though friction was probably high, as the entire drum's weight was only supported by the motor's bearing, which had been conceived for a plastic fan.



**Figure 33:** The dried struvite granules (diameter of the 1-rupee coin: 20 mm).



**Figure 34:** Production of granules from struvite powder: 1. Powder being added to the rotating drum, 2. Addition of water by means of a vaporizer, 3. Formation of low diameter granules, 4. Increase in granule diameter after few minutes, 5. The finished granules in the drum.

## 5.4 Outlook on the dissemination of struvite production

### 5.4.1 Economic viability of struvite production in Nepal

- *The technology of low-cost struvite production is ready for up-scaling.*
- *The economics of struvite production have to be examined from a broader perspective.*

The struvite production process from urine has shown to be efficient in the tested setting at pilot scale. The technology can be up-scaled without further limitations, preferably directly at a location with large urine production, in order to reduce input costs. However, from an economical perspective, the process still has major uncertainties. The cost for an up-scaled reactor can be estimated (Table 9). On the input side, the exact cost for the transport of the required salt brine volumes from India has to be estimated. In addition, formalities of the shipment have to be cleared, considering that the shipment could be held back due to undisclosed reasons, as happened to the second bittern sample.

At present DAP is sold at 25 NRs·kg<sup>-1</sup> (AIC, 2009) at the border entry point in Birganj. In the Kathmandu Valley the price reaches 40 to 50 NRs·kg<sup>-1</sup>. Struvite could be sold at a comparable price given its fertilizing properties. To be economically viable, the struvite production process needs to take into account the environmental and social value it produces, by reducing pollution through sewage input in surrounding surface waters, guaranteeing a local fertilizer production, and thereby reducing dependence from fertilizer imports, which follow the steadily increasing international prices. These aspects shall be addressed in a more detailed study of the economical context.

If struvite is produced in larger quantities, an adequate distribution chain needs to be developed. The commercialization of a struvite fertilizer product would require the close collaboration with experts in the field.

### 5.4.2 Dissemination and coordination workshop

On 11 June 2009, a dissemination and coordination workshop was held in the UN Conference Hall in Lalitpur. About 40 participants from various backgrounds attended the workshop and showed interest in struvite production. The audience recognized the work that has been done on the technological development, but expected further details concerning the economical aspects. In general, a small-scale business approach was welcomed, though the corresponding planning needs to be done and the viability demonstrated. From the agricultural side, a deeper study of the effects of struvite on the Nepalese soils and

**Table 9:** Cost breakdown of the pilot scale reactor and projected budget for an up-scaled reactor.

Reactor set-up	50 L	500 L
	NRs	NRs
steel tank for reactor	3'500	15'000
stirring system & stand	2'000	10'000
urine storage tank	500	8'000
pipes & fittings	500	2'000
effluent storage tank	500	8'000
<b>total [NRs]</b>	<b>7'000</b>	<b>43'000</b>

crops was suggested. The National Agriculture Research Council's (NARC) Soil Division would support a future struvite project in this aspect.

The need to emphasize the environmental benefits was also outlined. If 500 L of urine are required for the production of 1 kg struvite, which could be sold at a projected price of 50 NRs (0.50 €), the input and equipment costs cannot be compensated. An economical analysis needs to address environmental benefits, national food security, and independence from fertilizer imports in its balance.

The question, whether struvite can be recognized as an organic fertilizer or not, was extensively discussed during the end of the debate. As both perspectives have their valuable arguments, a clear definition has to be formulated prior to marketing struvite as an organic fertilizer. At the moment, there are no national guidelines for organic agriculture in Nepal. Products, which are marketed as 'organic', in particular the ones that are exported or aim at high-end target groups, frequently bear the labels of foreign certification agencies for organic agriculture (e.g. labels issued by Australia, the US, or the European Union).

### 5.4.3 Effluent reuse potential

For struvite production to fulfill the expectations of an environmental friendly technology, the issue of potential effluent reuse needs to be examined. Firstly, the effluent will still contaminate receiving waters, if released without further treatment, and secondly, it still contains valuable nutrients, which should be recovered for their reuse in agriculture. The reuse of effluent in drip-irrigation is a potential option, if agricultural surfaces are within reach of the struvite production site (John, 2009). For further nutrient recovery, research is still on-going. However, the fate of the effluent needs to be determined prior to the installation of an up-scaled struvite production plant.

# 6 Conclusion

The combination of laboratory tests and field experiments has brought the struvite recovery process to maturity. From a technological point of view, the process is ready for up-scaling, i.e. the low-cost struvite recovery process has been optimized, as this study had aimed for.

Furthermore, a broad interest prevails from the community side for experimentations at a larger magnitude. As separate urine collection has already been utilized, for instance from public toilets or commercial buildings, the additional infrastructure required for struvite production is restricted to the reactor itself, and an adequate effluent treatment.

However, before the process can be reproduced at will, a viable business approach has to be adopted. If struvite is sold at the present market price for phosphate-ammonium fertilizers (e.g. DAP), the financial investments for a struvite production facility may not be redeemed. For the production process to be economically viable, one needs to include the following considerations:

- By recovering nutrients from wastewater streams, struvite production engenders an environmental value; nutrient input, and subsequent eutrophication of receiving waters will be reduced.
- Local fertilizer production reduces the dependence on foreign imports and the vulnerability of the local market facing price changes at a global scale.
- The potential to sell a value added commodity produced from human waste streams may increase the incentive for improving sanitation in deprived communities.

Based on the experiences from 6 months pilot scale struvite production on the two reactor types in Siddhipur, a daily start-up treatment of 1000 L could be envisaged at one of the mentioned urine collection sites. At the average nutrient concentration found in stored urine during the field tests, this dimension would lead to the production of 2 kg struvite per day. A major technical challenge will be to remove the produced struvite powder from the filter bag and transform it into the final product without losses.

Running an up-scaled version of the struvite recovery reactor would allow the process to be adapted for further dissemination. At the same time, the production could function as a demonstration site for an initial exposure of interested user initiatives.

At present, it is important to keep the momentum in low-cost nutrient recovery practical research, in order to attain the dual benefit of improved sanitation and accessible agricultural inputs.

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# 9Annex

## 9.1 Optimization of liquid-solid separation

### 9.1.1 Comparison of filter arrays and filter materials

#### Lab tests of filter materials

P removal from urine (1 L) by struvite precipitation induced by bittern addition (10 mL) versus filter material (Figure 20):

filter	#	PO <sub>4</sub> -P <sub>in</sub> mg/L	PO <sub>4</sub> -P <sub>eff</sub> mg/L	removal %	filter	#	PO <sub>4</sub> -P <sub>in</sub> mg/L	PO <sub>4</sub> -P <sub>eff</sub> mg/L	removal %
paper 110	1-p1	170	7	96%	paper 110	5-p1	170	9	95%
paper 70	1-p2	170	8	95%	paper 70	5-p2	170	10	94%
paper 50	1-p3	170	11	94%	paper 50	5-p3	170	9	95%
nylon	1-n	170	8	95%	nylon	5-n	170	9	95%
cotton	1-c	170	8	95%	cotton	5-c	170	9	95%

TS removal from urine (1 L) by struvite precipitation induced by bittern addition (10 mL) versus filter material (Figure 21):

100mL	#	tare g	gross wt g	net wt g	TS mg/L	100mL	#	tare g	gross wt g	net wt g	TS mg/L
paper 110	1-p1	55.1271	55.3583	0.2312	9.248	paper 110	5-p1	59.3539	59.5912	0.2373	9.492
paper 70	1-p2	45.8380	46.0732	0.2352	9.408	paper 70	5-p2	59.1049	59.3457	0.2408	9.632
paper 50	1-p3	48.5938	48.8308	0.2370	9.480	paper 50	5-p3	62.7175	62.9565	0.2390	9.560
nylon	1-n	51.2222	51.4578	0.2356	9.424	nylon	5-n	65.4871	65.7255	0.2384	9.536
cotton	1-c	49.5464	49.7664	0.2200	8.800	cotton	5-c	63.9182	64.1558	0.2376	9.504

#### Field tests on filter arrays and filter cake buildup

Process parameters (Figure 22):

# description	date BS	date AD	in/eff	pH	EC	T	EC <sub>comp</sub>	P conc	flow <sub>cum</sub>	dilution	η <sub>removal</sub>
unit				-	mS/cm	°C	mS/cm	mg P/L	L	-	%
filter bag (1/2 size - 800 cm <sup>2</sup> )	2066/01/18	1.5.2009	in	8.96	20.1	24.9	20.1	130		10	
			eff	8.88	21.3	25.0	21.3	30	10	77%	
filter bag 1500 cm <sup>2</sup>	2066/01/24	7.5.2009	in	8.94	24.2	25.7	23.9	160		100	
			eff	8.90	25.2	25.1	25.1	15	10	91%	
filter bag 1500 cm <sup>2</sup>	2066/01/25	8.5.2009	in	8.90	25.3	25.3	25.1	146		10	
			eff	8.88	27.1	25.3	26.9	16	10	89%	
filter bag 1500 cm <sup>2</sup> (leakage)	2066/02/04	18.5.2009	in	8.81	26.2	25.0	26.2	170		100	
			eff	8.76	26.6	25.1	26.5	30	10	82%	
filter bag 1500 cm <sup>2</sup> time series	2066/02/08	22.5.2009	in	8.59	22.6	26.6	21.9	210		100	
			eff 0 min	8.86	21.9	25.6	21.6	35	0	10	83%
			eff 1 min	8.70	22.4	25.5	22.2	20	18	10	90%
			eff 2 min	8.94	21.4	25.3	21.3	15	32	10	93%
			eff 5 min	8.74	21.8	25.4	21.6	9	45	10	96%
filter bag 2000 cm <sup>2</sup> time series	2066/02/21	4.6.2009	in	8.92	20.6	26.0	20.2	119		10	
			eff 0 min	8.82	27.1	26.1	26.5	23	0	10	81%
			eff 1 min	8.88	21.4	26.0	21.0	16	8	10	87%
			eff 2 min	8.88	20.9	25.8	20.6	15	15	10	87%
			eff 5 min	8.86	20.9	25.6	20.7	9	28	10	92%
			eff 10 min	8.83	20.9	26.1	20.5	9	42	10	92%
eff 20 min	8.80	21.0	26.0	20.6	8	48	10	93%			

## 9.1.2 Examination of granulometric distribution and sedimentation velocity of struvite

### Validation of hydrometer and pipette method for struvite sedimentation

Series of hydrometer readings and density measurements versus sedimentation time (Figure 24):

time	hydrometer reading	density 1	density 2	density 3	median	max dev	min dev	stand dev
min	g TSS/L	g/mL	g/mL	g/mL	g/mL	g/mL	g/mL	g/mL
0	31	0.9958	1.0107	1.0103	1.0103	0.0004	0.0145	0.0084
2	31	0.9983	1.0073	1.0083	1.0073	0.0010	0.0090	0.0055
5	31	0.9866	1.0077	1.0059	1.0059	0.0018	0.0193	0.0116
10	31	0.9977	1.0120	1.0080	1.0080	0.0040	0.0103	0.0073
30	31	0.9835	1.0036	1.0170	1.0036	0.0134	0.0201	0.0168
60	29	0.9836	0.9942	0.9988	0.9942	0.0046	0.0106	0.0077
90	28	0.9763	0.9940	0.9928	0.9928	0.0012	0.0165	0.0098

Series of TS measurements versus sedimentation time (Figure 25):

time	tare	gross wt	net wt	TS	TS
min	g	g	g	g/L	g/L
0	55.8038	56.1396	0.3358	13.43	0.00
2	54.8754	55.1980	0.3226	12.90	-0.53
5	56.0367	56.3470	0.3103	12.41	-1.02
10	56.5143	56.8109	0.2966	11.86	-1.57
30	56.5623	56.8568	0.2945	11.78	-1.65
60	48.9610	49.2650	0.3040	12.16	-1.27
90	48.5947	48.8961	0.3014	12.06	-1.38

## 9.1.3 Testing of the effects of flocculants on recovery efficiency and settling velocity

### Comparison of the effects of flocculants on sedimentation

TS removal caused by flocculants (at 10 cm depth) versus time (Figure 26 and Figure 28):

time	bittern					bittern & ensola 2001					bittern & ensola 2051				
	#	tare	gross wt	TS	rel	#	tare	gross wt	TS	rel	#	tare	gross wt	TS	rel
		g	g	g/L	g/L		g	g	g/L	g/L		g	g	g/L	g/L
0	1-0	56.5619	56.8326	10.828	0.00	2-0	48.9608	49.2361	11.012	0.00	3-0	55.314	55.5809	10.676	0.00
10 min	1-10	52.0001	52.2557	10.224	-0.60	2-10	56.4791	56.7424	10.532	-0.48	3-10	56.0808	56.3433	10.5	-0.18
1 h	1-1	59.3549	59.6155	10.424	-0.40	2-1	65.4869	65.7496	10.508	-0.50	3-1	62.7183	62.9799	10.464	-0.21
1 d	1-X	59.1057	59.3628	10.284	-0.54	2-X	66.2928	66.5506	10.312	-0.70	3-X	69.6313	69.8899	10.344	-0.33

time	bittern & alum					bittern & lime				
	#	tare	gross wt	TS	rel	#	tare	gross wt	TS	rel
		g	g	g/L	g/L		g	g	g/L	g/L
0	4-0	55.8026	56.0861	11.34	0.00	5-0	56.5135	56.7858	10.892	0.00
10 min	4-10	54.875	55.1397	10.588	-0.75	5-10	56.037	56.2937	10.268	-0.62
1 h	4-1	65.3197	65.5793	10.384	-0.96	5-1	65.28	65.5391	10.364	-0.53
1 d	4-X	66.5178	66.7785	10.428	-0.91	5-X	65.288	65.5453	10.292	-0.60

time	bittern					moringa seeds (50mg/L)					bittern & moringa seeds (50mg/L)				
	#	tare	gross wt	TS	rel	#	tare	gross wt	TS	rel	#	tare	gross wt	TS	rel
		g	g	g/L	g/L		g	g	g/L	g/L		g	g	g/L	g/L
0	1-0	56.0355	56.3063	10.832	0.00	2-0	45.8369	46.0049	6.72	0.00	3-0	49.5455	49.812	10.66	0.00
10 min	1-10	48.5936	48.8480	10.176	-0.66	2-10	55.1268	55.2917	6.596	-0.12	3-10	58.3314	58.5835	10.084	-0.58
1 hour	1-1	56.5137	56.7635	9.992	-0.84	2-1	55.8031	55.9677	6.584	-0.14	3-1	55.3142	55.5665	10.092	-0.57
1 day	1-x	69.6282	69.8601	9.276	-0.84	2-x	64.0687	64.2301	6.456	-0.26	3-x	65.2801	65.5360	10.236	-0.42

time	bittern II				bittern & moringa seeds (500mg/L)					
	#	tare	gross wt	rel	#	tare	gross wt	TS	rel	
		g	g	g/L		g	g	g/L	g/L	
0	2-0	51.2361	51.4754	9.572	0.00	1-0	65.3188	65.59	10.848	0.00
10 min	2-10	54.8942	55.1147	8.82	-0.75	1-10	63.9161	64.1685	10.096	-0.75
1 hour	2-1	48.9982	49.2004	8.088	-1.48	1-1	62.7164	62.9698	10.136	-0.71
1 day	2-x	48.5944	48.8350	9.624		1-x	59.1040	59.3586	10.184	-0.66

## 9.2 Standard addition

### 9.2.1 Standard addition Nessler method for $\text{NH}_4^+$ analysis

Date: 10 December 2008  
 Instrument: HACH DR 2000  
 Matrix: diluted urine (1:10'000)  
 Wavelength: 380 nm  
 Standard: Merck 1000 mg  $\text{NH}_4^+\cdot\text{L}^{-1}$

#### Linear adjustment curve

Standard #	reading $y_i$	concentration $x_i$	value
	-	mg N·L <sup>-1</sup>	mg N·L <sup>-1</sup>
1	1.35	1.94	1.92
2	1.19	1.70	1.69
3	1.03	1.46	1.46
4	0.87	1.22	1.22
5	0.72	0.97	1.01
6	0.54	0.73	0.75
7	0.36	0.49	0.48
8	0.17	0.24	0.21

#### Method standard deviation:

$$s_{x_0} = 0.025 \text{ [mg N}\cdot\text{L}^{-1}\text{]}$$

#### Addition

Addition #	reading Y	value X <sub>gefunden</sub>	$\Delta_{\text{target}}$	$\Delta_{\text{found}}$
	-	mg N·L <sup>-1</sup>	mg N·L <sup>-1</sup>	mg N·L <sup>-1</sup>
1			0.00	0.00
2	0.35	0.46	0.08	0.50
3	0.50	0.69	0.15	0.73
4	0.51	0.70	0.23	0.75
5	0.51	0.70	0.30	0.74
6	0.54	0.75	0.37	0.79
7	0.61	0.84	0.45	0.88
8	0.67	0.93	0.52	0.97

#### Coefficients of retrieval function (95% confidence interval)

$$b = 0.85 \text{ (0.45...1.24)}$$

$$a = 0.51 \text{ (0.38...0.64)}$$

#### Standard deviation of retrieval function:

$$s_{y_f} = 0.060 \text{ [mg N}\cdot\text{L}^{-1}\text{]}$$

## 9.2.2 Standard addition molybdovanadate method for P analysis

Date: 3 December 2008  
 Instrument: HACH DR 2000  
 Matrix: diluted urine (1:100)  
 Wavelength: 430 nm  
 Standard: Merck 1000 mg PO<sub>4</sub><sup>3-</sup>·L<sup>-1</sup>

### Addition

Addition #.	standard volume	[PO <sub>4</sub> <sup>3-</sup> ] target	[PO <sub>4</sub> <sup>3-</sup> ] actual	difference
	m·L <sup>-1</sup>	mg·L <sup>-1</sup>	mg·L <sup>-1</sup>	
1	0.00	8.5	8.5	0
2	0.05	10.5	10.7	0.2
3	0.10	12.5	12.4	-0.1
4	0.15	14.5	14.6	0.1
5	0.20	16.5	17.2	0.7
6	0.25	18.5	18.7	0.2
7	0.30	20.5	20.7	0.2

### Method standard deviation:

0.3 [mg PO<sub>4</sub>·L<sup>-1</sup>] or 0.098 [mg PO<sub>4</sub>-P·L<sup>-1</sup>]

### Pipet test Socorex 100 - 1000 µL and 10 - 100 µL

Date: 5 September 2008  
 Density 25°C: 0.997 g/ml

#### Pipet Socorex 06072637 100-1000µL

preset [ml]	1	0.5	0.1
	g	g	g
1	0.990	0.496	0.098
2	0.989	0.496	0.099
3	0.987	0.497	0.099
4	0.989	0.495	0.100
5	0.990	0.497	0.100
6	0.989	0.495	0.099
7	0.991	0.500	0.100
8	0.991	0.500	0.100
9	0.991	0.496	0.100
10	0.995	0.497	0.100
average	0.990	0.497	0.099
st dev	0.002	0.002	0.001
CV [%]	0.21	0.39	0.72

#### Pipet Socorex 12081204 10 - 100 µL

preset [ml]	0.1	0.05	0.01
	g	g	g
1	0.099	0.049	0.010
2	0.099	0.049	0.009
3	0.099	0.049	0.010
4	0.099	0.049	0.010
5	0.099	0.049	0.009
6	0.099	0.049	0.010
7	0.099	0.049	0.010
8	0.099	0.049	0.010
9	0.099	0.049	0.009
10	0.099	0.049	0.010
average	0.099	0.049	0.009
st dev	0.000	0.000	0.000
CV [%]	0.22	0.27	1.99

## 9.3 STUN struvite brochure (outside)

### Installation procedure

- assembly of reactor container (sheet metal tank with conical bottom) according to treatment volume (1 L reactor per 10 L of urine per day)
- construction of stirring mechanism & stand (welded metal bars and sheet); assure flow from storage to reactor to disposal
- installation of fittings & filter (polypropylene fittings and nylon filter bag). Filter fabric: nylon fabric as used for shirts sewn to bag of 0.4 m<sup>2</sup> surface for 100 L reactor.
- set-up of reactor and storage tanks (plastic storage tanks with connections to reactor)

### Dimensioning

- daily treatment capacity: 10 L urine / 1 L reactor
- 500 L urine yield approximately 1 kg struvite

### Installation costs

- labour costs: 1 operator for a 500 L reactor

Reactor set-up [NR\$]	50 L	500 L
steel tank for reactor	3'500	15'000
stirring system & stand	2'000	10'000
urine storage tank	500	8'000
pipes & fittings	500	2'000
effluent storage tank	500	8'000
<b>total [NR\$]</b>	<b>7'000</b>	<b>43'000</b>

### Further considerations

- small scale business approach
- commercialization of struvite as a fertilizer
- phosphorous prices are likely to increase further
- transportation of bittern from India to Nepal

### Further readings

- Etter, B. (2009): Struvite recovery from urine at community scale in Nepal – Project intermediate report. EPFL, Swiss Federal Institute of Technology, Lausanne, Switzerland
- Etter, B. (2009): Process optimization of low-cost struvite recovery – MSc thesis. EPFL, Swiss Federal Institute of Technology, Lausanne, Switzerland
- Gartenbein, B., Knadka, R. (2009): Struvite recovery from urine at community scale in Nepal – Final project report phase 1. Eawag: Swiss Federal Institute of Aquatic Science and Technology, Zurich, Switzerland
- Tilley, E., Gartenbein, B., Knadka, R., Zurbrugg, C., Uderl, K.M. (2009): Social and economic feasibility of struvite recovery from urine at the community level in Nepal. In: International Conference on Nutrient Recovery from Wastewater Streams. K. Ashley, D. Mawhin and F. Koch (eds). IWA Publishing, London, pp 169-178.

> Download the publications from [www.sandec.ch](http://www.sandec.ch)

### Internet resources

- [www.novazquats.ch](http://www.novazquats.ch)
- [www.sandec.ch](http://www.sandec.ch)
- [www.ceep-phosphates.org](http://www.ceep-phosphates.org)

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**UN-HABITAT**  
FOR A BETTER URBAN FUTURE

**eawag**  
aquatic research

**How to produce  
fertilizer from urine:  
Struvite**



Urine contains valuable nutrients: it is an excellent fertilizer if applied to crops.

Struvite is a powder fertilizer produced from urine.

If urine cannot be applied directly because:

- storage space is not available
- transport is difficult
- its odour is unpleasant

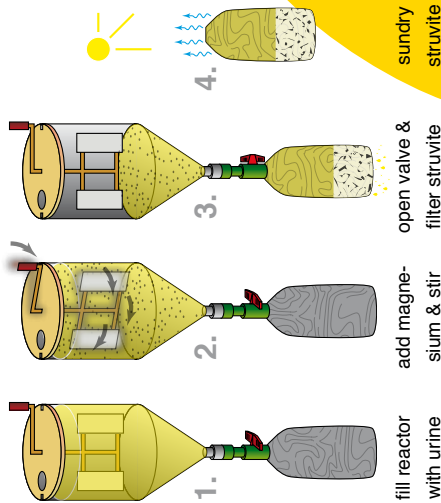
You can produce struvite to benefit from the fertilizing properties of urine, because:

- volume and weight are reduced
- nutrients can be stored over time
- handling is more user-friendly in powder form

Eawag: Swiss Federal Institute of Aquatic Science and Technology  
UN-HABITAT: The United Nations Human Settlement Programme

# STUN struvite brochure (inside)

## How does the STUN reactor work?



## Process inputs

### urine

#### urine harvesting

- from urine diverting toilets
- from urinals
- on markets
- in public buildings etc.

### magnesium

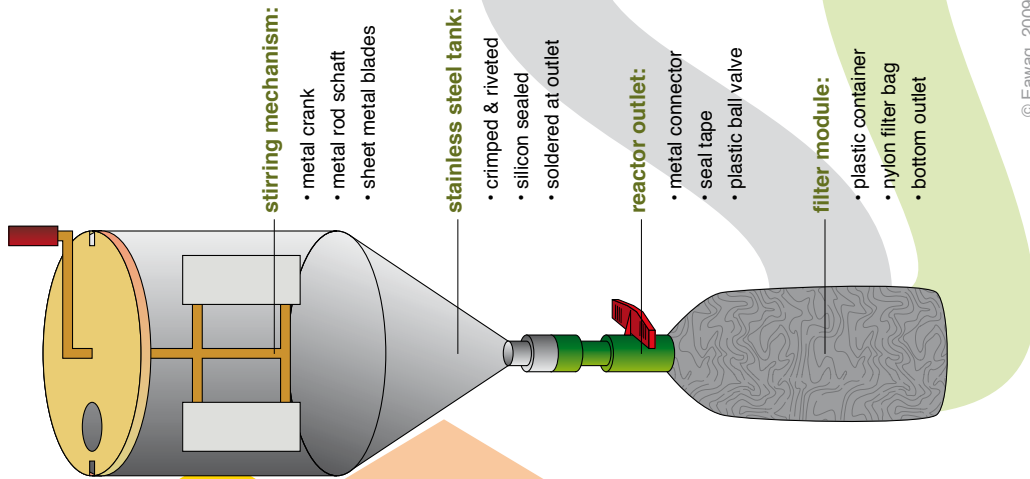
#### magnesium (Mg) sources

- magnesium sulphate ( $MgSO_4$ ): fertilizer powder  
magnesium content: 5 - 10%
- bittern: waste product of salt production  
magnesium content: 3 - 10%

#### magnesium (Mg) dosage

- determine phosphorus (P) content in urine
- Mg:P molar ratio 1:1:1

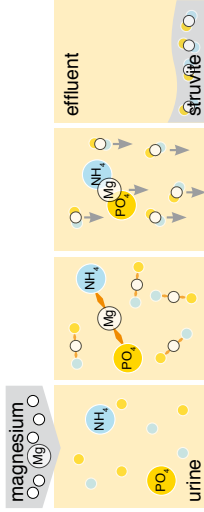
## STUN: Struvite recovery from urine in Nepal The Struvite Harvesting Reactor



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## 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.



## Process outputs

### struvite as fertilizer

#### fertilizer comparison (N:P:K)

urea	N	46:0:0
DAP	N P	18:46:0
struvite	N P Mg	6:29:0+10Mg

#### struvite in practice – a valuable fertilizer

- slow-release – continuous nutrient flow
- bio-available – easy uptake by plants
- free of heavy metals and pharmaceuticals

### effluent reuse potential

#### effluent characteristics – additional nutrients

- high nitrogen (N) content
- high potassium (K) content

#### reuse potential – fertigation

- fertigation: fertilization by irrigation
- no clogging in drip irrigation

Process optimization of low-cost  
**struvite recovery**

MSc thesis

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