

## Human Urine – Decomposition Processes and Nutrient Recovery

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### Abstract

A process to recover nutrients from human urine was tested at the Institute of Environmental Engineering (ISA) of RWTH Aachen University. Before testing the recovery process the urine was stored and the decomposition processes during this period were observed. Throughout the storage the pH value and the concentration of ammonia nitrogen increased, the concentration of phosphate phosphorus decreased. These variances can be speed up by addition of urease. The recovery process - so-called NuReBas-process – consists of a phosphorus recovery process followed by a nitrogen recovery process. The phosphorus recovery step is easy to handle and approx. 99% of the load of phosphate phosphorus were eliminated and transferred into the product. Analysing the product indicators for struvite could be identified. The final step of the process is the stripping of the remaining ammonia-nitrogen by air followed by a gas scrubber.

### Keywords

decomposition processes, human urine, nutrient recovery, pharmaceuticals, phosphorus, struvite

## INTRODUCTION

At the Institute of Environmental Engineering (ISA) of RWTH Aachen University several research and development projects concerning the field of nutrient recovery have been carried out. In the context of these projects the decomposition processes during the storage of human urine were observed and a process to recover phosphorus and nitrogen from the stored urine was tested. The phosphorus recovery is based on struvite crystallization and the nitrogen recovery on the well-known stripping process. Precondition for nutrient recovery is the use of no-mix-toilets separating urine and faeces. These toilets have been integrated in some new settlements in Germany provided with ecological sanitary systems.

## DESCRIPTION OF THE PROCESSES AND RESULTS

### Decomposition processes during storage of human urine

The major plant nutrients nitrogen and phosphorus are found in the human excreta and thus in domestic wastewater. The content of them vary depending on the eating habits.

Using no-mix-toilets there are two effluents: urine and faeces. Regarding the nutrients the following allocation (table 1) was noticed:

Table 1: Allocation of nutrients in human urine and faeces (SCHÖNNING, 2007)

	urine	faeces
phosphorus	> 55%	< 45%
nitrogen	> 80%	< 20%

At most of the places using no-mix-toilets the urine is stored before it will be treated. The composition of fresh human urine and stored urine is shown in table 2. The data of the stored urine are taken from literature and from experiments carried out at the Institute of Environmental Engineering (ISA) of RWTH Aachen University.

Table 2: Composition of fresh and stored human urine from different places

		fresh urine	stored urine - workplace CH	stored urine - residential area S	stored urine - residential area S	stored urine - residential area D
pH value	[-]	6.2	9.1	9.1	9.2 - 9.3	9.15
COD	[mg/ L]	12,000	10,000	n.i.	2,200 - 2,800	n.i.
nitrogen	[mg/ L]	9,200	9,200	3,631	n.i.	9,000
phosphorus	[mg/ L]	1,000	540	313	170 - 240	344
sulphur	[mg/ L]	1,000	n.i.	331	n.i.	314
calcium	[mg/ L]	170	0	18	n.i.	13
magnesium	[mg/ L]	100	0	11	n.i.	1.9
sodium	[mg/ L]	4,200	2,600	1,210	n.i.	2,510
potassium	[mg/ L]	2,200	2,200	1,000	n.i.	1,200
chlorine	[mg/ L]	3,800	3,800	1,768	n.i.	n.i.
reference		CIBA GEIGY (1977)	MAURER et al. (2006)	JÖNSSON et al. (1997)	EK et al. (2006)	experiments at the Institute of Environmental Engineering (ISA)
legend: COD = chemical oxygen demand; n.i. = no information						

For the experiments carried out at the Institute of Environmental Engineering (ISA) the human urine was collected and stored in tanks with a volume of 1,000 litres. After collection the fresh urine showed a pH value of 6.5, the concentration of ammonium nitrogen was 190 mg NH<sub>4</sub>-N/L and that of phosphate phosphorus was 164 mg PO<sub>4</sub>-P/L. During the storage these three parameters altered because of decomposition processes. The pH value and the concentration of ammonium nitrogen increased. But the concentration of phosphate phosphorus decreased a little. Literature describes that the addition of urease assists to speed up these changes. In the following three figures (figure 1, figure 2, and figure 3) those three mentioned parameters are presented, which were analysed in the human urine over a period of 246 days.

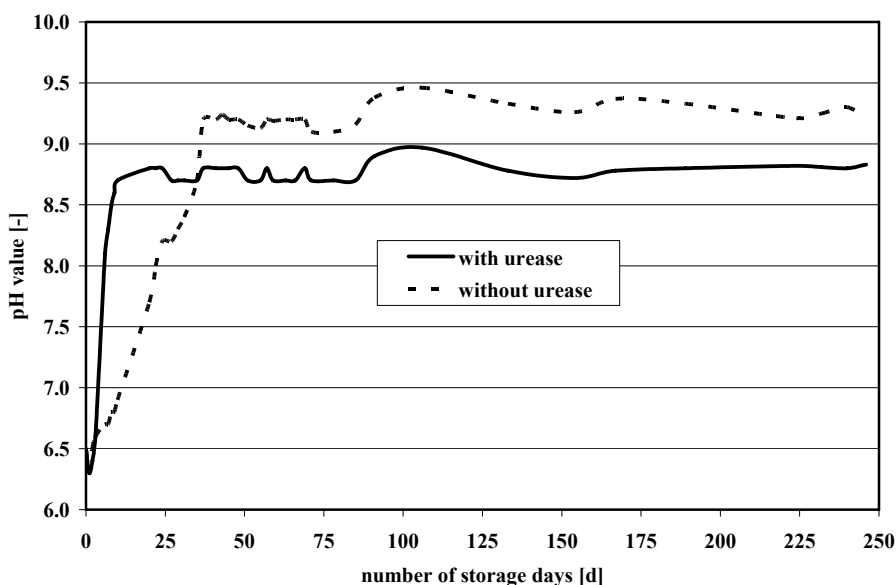


Figure 1: Variances of the pH value during the storage of human urine

After the addition of urease the pH value increases from 6.5 up to 8.8 within 10 days of storage. Without the aid of urease the urine shows a final pH value of 9.2. To achieve this value it takes approx. 40 days.

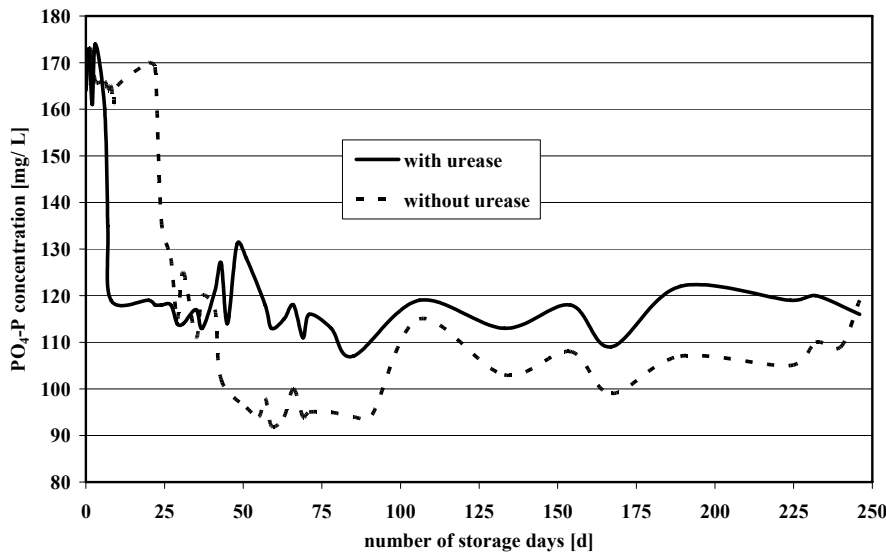


Figure 2: Variances of the phosphate phosphorus concentration during the storage of human urine

At the beginning of the storage the concentration of phosphate phosphorus was 164 mg PO<sub>4</sub>-P/L. The concentration decreases to approx. 110 mg PO<sub>4</sub>-P/L because of the increasing pH value and the succeeding processes of precipitation. After this decrease the concentration was nearly constant. Without the aid of urease it takes approx. 30 days to achieve this level, with the aid of urease it takes only ten days.

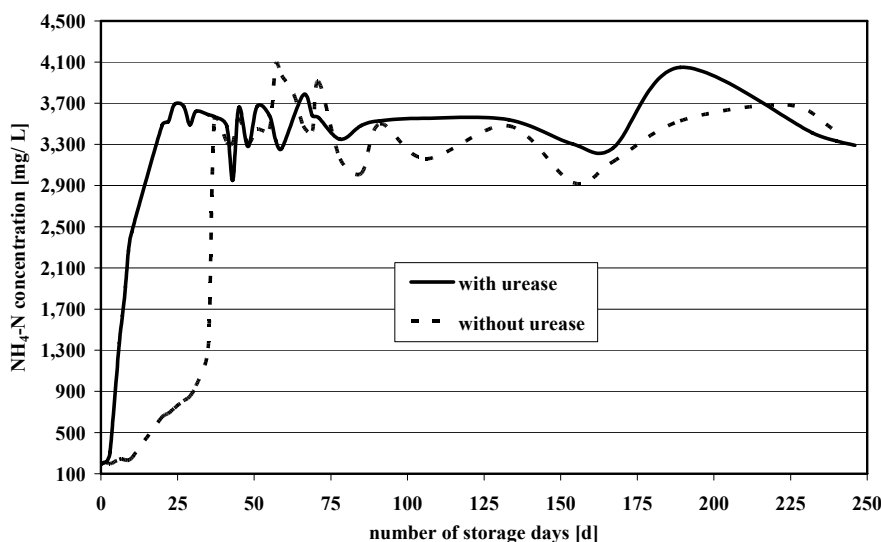


Figure 3: Variances of the ammonium nitrogen concentration during the storage of human urine

Because of decomposition processes the concentration of ammonium nitrogen increases from 190 mg NH<sub>4</sub>-N/L to approx. 3,500 mg NH<sub>4</sub>-N/L towards the end of storage. This concentration is the final one, there are no variances after achieving. Also the same temporal phenomenon can be

identified. To achieve this constant concentration of ammonium nitrogen it takes 40 days without the aid of urease and only 25 days with the aid of urease.

It can be stated that the addition of urease only speeds up the variances of the three observed parameters and the total values of pH and of the nutrient concentrations are not dependent on this.

Urine of a healthy human is amicrobic. Microorganisms are only present in urine of sick humans. Storage significantly lowers the number of microorganisms in urine (table 3).

*Table 3: Storage time for 90 % reduction of selected microorganisms in human urine (pH = 9) (SCHÖNNING, 2007)*

	time [d] for 90 % reduction of				
	gram-negative bacteria	gram-positive bacteria	Cryptosporidium parvum	Rhesus rotavirus	Salmonella typhimurium (phage 28B)
urine storage at 4 °C	1	30	29	172	1,466
urine storage at 20 °C	1	5	5	35	71

The findings in table 3 show that more than 90 % of bacteria, protozoa and viruses are eliminated after eleven-week storage at a temperature of 20 °C (SCHÖNNING, 2007). A storage at lower temperature leads to longer storage time. Storage at a temperature of 4 °C needs 210 weeks for an elimination rate of 90 % (SCHÖNNING, 2007). Reason for this phenomenon is that the dissociation balance is moved in favour of ammonia nitrogen at higher temperatures. Thus, the microorganisms are killed not only by the high pH value (pH = 9) but also by the high concentration of ammonia nitrogen.

Most of the administered pharmaceuticals are used only to a minor part by the human body. The overplus of pharmaceuticals and of pharmaceutical residues respectively is excreted with the urine. At present experiments on the decomposition of active pharmaceutical ingredients during the storage of the urine are carried out. In table 4 the elimination rate of Erythromycin, which is an often used antibiotic for the treatment of different bacterial infections, is exemplified.

*Table 4: Elimination rate of Erythromycin*

	concentration of Erythromycin [µg/ L]		
	fresh urine	stored urine	
		5 weeks at 4°C	5 weeks at 4°C + 3 weeks at 20°C
sample 1	1.9	1.7	0.9
sample 2	1.2	1.0	0.6

Regarding the decomposition rate of Erythromycin it can be stated that the basic conditions must be analogue to them of the elimination of microorganisms. By storage at a temperature of 20 °C the concentration of “Erythromycin” in the urine can be lowered significantly.

### Nutrient recovery process from human urine

For the treatment of human urine a wide variety of technologies can be used. MAURER et al. (2006) defined seven main purposes of a treatment unit: hygienisation, volume reduction, stabilisation, phosphorus recovery, nitrogen recovery, biological nutrient removal and removal of micro-pollutants. Table 5 gives an overview of the currently known urine treatment processes. In addition, the processes are discussed concerning their efficiencies for phosphorus and nitrogen recovery.

Table 5: Overview of the urine treatment processes (MAURER et al., 2006; modified)

	hygienisation		volume reduction			stabilisation			P-recovery	N-recovery				nutrient removal	micropollution removal		
	storage	evaporation	freeze-thaw	reverse osmosis	acidification	microfiltration	nitrification	struvite precipitation	ion exchange	struvite precipitation	NH <sub>3</sub> stripping	isobutyraldehyde-diurea precipitation	Anammox process	electrodialysis	nanofiltration	ozonation	
P-recovery	•	++	++	++	•	•	•	++	•	++	•	•	•	+	•	•	
N-recovery	•	++	++	++	•	•	•	+	++	++	++	++	•	+	•	•	

legend: • no effect, + positive effect, ++ strong effect

As seen in table 5 the volume reduction processes and struvite precipitation show a strong effect on phosphorus and nitrogen recovery.

Based on these results the NuReBas-process (NuReBas = nutrient recovery with bag filtration systems; DE 102006043246.0) for urine treatment was developed at the Institute of Environmental Engineering (ISA) at RWTH Aachen University. As shown in figure 4 the NuReBas-process consists of a phosphorus recovery process (struvite crystallization) and a nitrogen recovery process (ammonia nitrogen stripping). The phosphorus recovery process is made up of a collecting tank and a bag filter housings and is being tested in pilot-scale experiments. The nitrogen recovery process is made up of a stripping tank and a gas scrubber. Between both processes an intermediate tank is interposed.

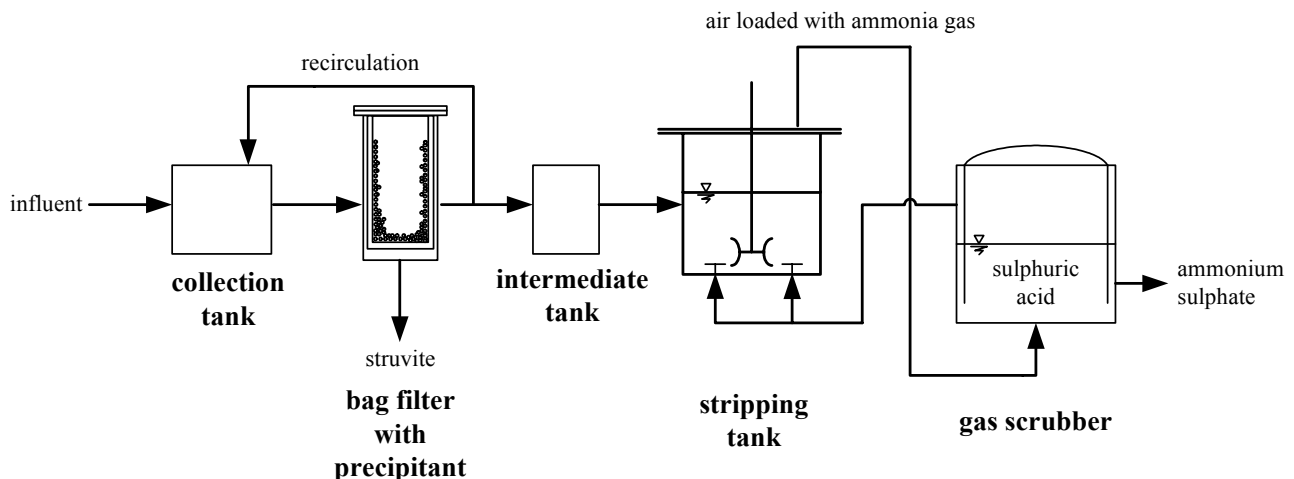
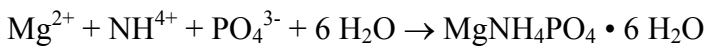


Figure 4: Flow chart of the NuReBas-process (DE 102006043246.0)

The collection tank has a volume of 200 litres. The bag filter housings is made of stainless steel and can operate with a pressure up to 800 kPA and a flow rate up to 35 m<sup>3</sup>/h. The filtration surface is 0.5 m<sup>2</sup>. The bag filter is made of nylon texture with a pore size of 50 µm.

The urine which was used to test the NuReBas-process has been stored for nearly eight months. Thus the urine shows a pH value of approx. 9. This pH value supports the recovery process because the recovery of phosphorus by struvite crystallization works ideal at pH values between 9.0 and 9.5. The chemical reaction of the struvite crystallization is:



To accomplish the chemical reaction magnesium is added as a precipitant in form of magnesium oxide powder or magnesium chloride. For each experiment the collecting tank was filled with 180 litres of human urine. The urine was circulated through the bag filter housings using a rotary pump. The special feature of the process is that the used magnesium compound is added directly in the bag filter. The mass of the added magnesium compound is dependent on the phosphate phosphorus concentration in the urine. A molar ratio of Mg / P = 2 / 1 has been used.

The results of four experiments are shown in table 6.

*Table 6: Phosphorus recovery process - results of four experiments*

	precipitant		influent			effluent after 120 minutes		recovery rate	
	type	dosage with molar ratio Mg:P	pH value	PO <sub>4</sub> -P	NH <sub>4</sub> -N	PO <sub>4</sub> -P	NH <sub>4</sub> -N	PO <sub>4</sub> -P	NH <sub>4</sub> -N
			[-]	[mg/ L]	[mg/ L]	[mg/ L]	[mg/ L]	[%]	[%]
experiment 1	MgO	2 : 1	9.01	396	4,700	3.10	4,233	99.22	9.94
experiment 2	MgCl <sub>2</sub>	2 : 1	9.06	361	4,208	2.20	3,904	99.39	7.22
experiment 3	MgO	2 : 1	9.16	933	4,181	0.55	3,668	99.94	12.27
experiment 4	MgO	1,5 : 1	9.16	933	4,181	0.41	4,040	99.96	3.37

In all four experiments the recovery rate of phosphate phosphorus was approx. 99 % and of ammonium nitrogen between 3 and 12 %. Nearly the complete phosphate phosphorus load was transferred into the product struvite. Reason for the low recovery rate of ammonium nitrogen is that the compound ratio in struvite is Mg : NH<sub>4</sub> : PO<sub>4</sub> = 1 : 1 : 1 and thus ammonium nitrogen abounds in urine.

In figure 5 the variances of the phosphate phosphorus and ammonium nitrogen concentration of experiment 1 and 3 subject to the time of filtration are exemplified.

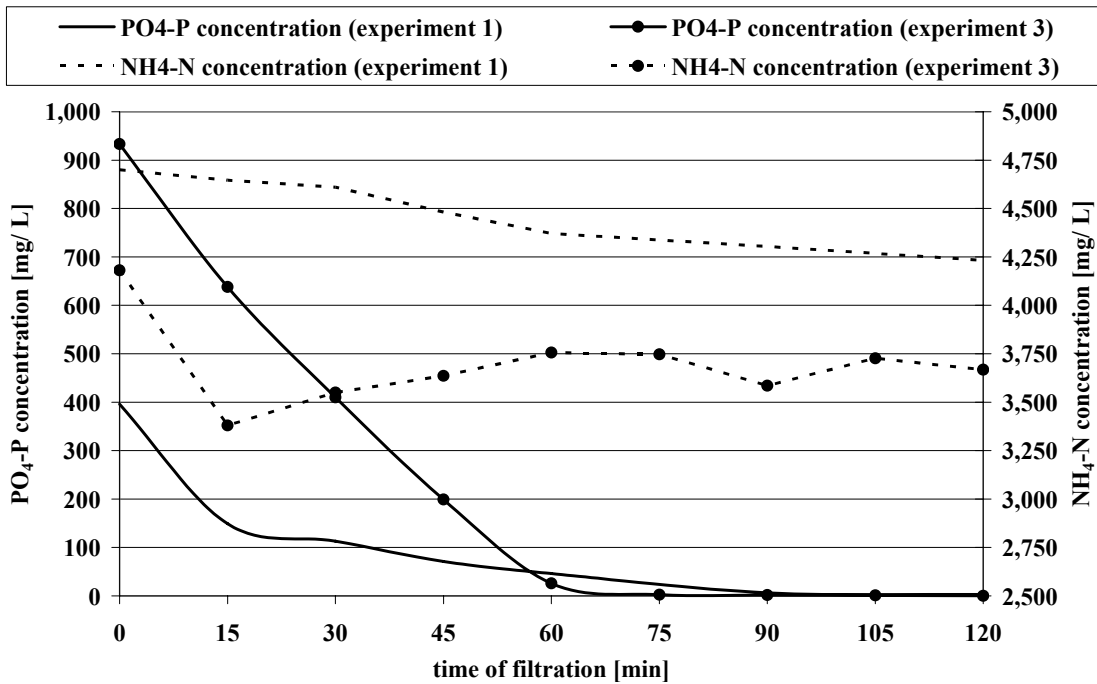


Figure 5: Result of experiment 1 and 3 - PO<sub>4</sub>-P concentration and NH<sub>4</sub>-N concentration subject to the time of filtration

Within 60 minutes the PO<sub>4</sub>-P concentration in the urine highly decreased, which complies with a recovery rate of approx. 90 %. After 120 minutes 99 % of the phosphate phosphorus load was recovered and thus transferred into the product. Evaluating the product a microscopic picture was made (figure 6).



Figure 6: Microscopic picture of the product (400-times magnified)

The struvite crystal has two main forms. One of the forms resembles a coffin lid and the other form is shaped like the letter “X”. Typical struvite crystals – the “x”-form – can be identified in figure 6, which is an indicator, that the process recovers phosphorus based on struvite crystallization.

The final step of the NuReBas-process is the stripping of the remaining ammonium nitrogen by air followed by a gas scrubber. At present experiments on this stripping process are carried out and will be tested in pilot-scale experiments. The pilot plant is made up of a stripping tank and a gas scrubber.

After the phosphorus recovery process the urine will be discharged into the stripping tank and heated up to approx. 60°C. At this temperature the urine will be stirred up and stripped by air injec-

tion. Because of these conditions the ammonium nitrogen of the human urine will react and pass over into the gas phase as ammonia gas.

The ammonia enriched air will be discharged into the gas scrubber which is filled with high concentrated sulphuric acid (approx. pH of 1). The sulphuric acid reacts with the ammonia enriched air and forms ammonium sulphate. The capacity of the gas scrubber will be monitored by measuring by the pH value, because the described reaction leads to an increase of the pH value. Achieving a pH value of approx. 6 the sulphuric acid has to be replaced.

## CONCLUSIONS

The described NuReBas-process is a process for nutrient recovery from human urine. One important advantage of this process is that it is composed of ready-made components and thus it can be adapted to the points of use (size, flow rate etc.).

The phosphorus recovery process based on struvite crystallization is easy to handle and needs only marginal consumption of additives. The most important additive is the magnesium compound. The bag filter can be cleaned and thus it can be used several times. Producing struvite has two main advantages. The first advantage is that struvite can directly be used as a fertiliser and the second that the crystallization of struvite avoids widely the integration of harmful substances.

The nitrogen recovery process is based on ammonia nitrogen stripping which is a well-known and approved technique. The product of the stripping process – ammonium sulphate – is also valuable, because it is a raw material of the fertilizer industry.

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