Urine Treatment – Absolute Flexibility

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What happens to urine after it has been collected? The particular characteristics of this liquid permit a wide range of treatment methods. These can be used to modify the unusual resource as required – e. g. to remove specific pollutants or to produce a fertilizer. The suitability of a number of processes has been assessed by Eawag.

NoMix technology allows separate treatment of urine. However, customized processes have to be developed to treat this special liquid (Tab. 1 and Box). Our aim was therefore to identify methods that could be applied in practice. For this purpose, we performed a literature search for procedures that had previously been used in connection with urine. In addition, further processes were tested in Eawag laboratories to determine their suitability for urine treatment. Our studies yielded a broad range of methods for hygienization and stabilization, for the removal and inactivation of organic micropollutants, and for the recovery and elimination of nutrients (Tab. 2; for details see [1]). While these procedures ensure a high degree of flexibility in urine treatment, it will usually be necessary – depending on the specific aims of urine source separation – to combine various methods within a treatment unit (see also the article by Wouter Pronk on p. 20).

Hygienization Through Urine Storage. Collected urine may contain pathogenic organisms, deriving either from patients or from contamination with faeces. The simplest way of hygienizing urine is to store it for a period of several months. The crucial factor in this process is the storage temperature. Tests have shown that storage of urine at 20 °C for 6 months is sufficient to obtain a perfectly hygienic state. Although numerous other treatment options exist, such as exposure to ultraviolet light or high-pressure processing, they have never been tested on urine.

Stabilization with Acid or Biological Treatment. In certain cases, urine should be stabilized prior to further treatment. This allows labile substances in the urine to be preserved or eliminated so as to prevent unpleasant odours and environmental impacts from toxic ammonia emissions.

Fresh urine can be preserved by the addition of a strong acid, e. g. 2.9 g/l of concentrated sulphuric acid, since urine is stable below pH 4. This method of preparation is also used when water is to be recovered from urine on lengthy space missions. By contrast, sterile filtration – another method that we tested – proved not to be suitable in practice because the enzymes responsible for decomposition are present in dissolved form in urine, and were still able to pass through the filter.

Alternatively, urine that is already decomposed can be stabilized by means of biological treatment. Our experience with this approach involved a variety of bioreactor configurations. In this process, the readily degradable organic substances are broken down by bacteria and, in addition, through nitrification (conversion of ammonia to nitrite and nitrate by aerobic bacteria), the pH of the urine is lowered and volatile ammonia is removed. The extent of nitrification varies according to the reactor configuration, and an odourless ammonium nitrate or ammonium nitrite solution is obtained.

The nitrate solution could subsequently be used as a rapidly acting liquid fertilizer, while the nitrite solution could be processed further in an anaerobic ammonium oxidation reactor. In the so-called anammox reaction, ammonium is converted to molecular

Tab. 1: Chemical composition of collected, stored urine from a household with water-flushed urine diverting toilets [2] and from the Eawag office building with water-free urinals [3], compared with fresh urine [4].
COD = chemical oxygen demand, a measure of the organic components.

	Stored urine With flushing water Household	Without flushing water Office building	**Fresh urine** Undiluted Literature data
Dilution $V_{urine} / (V_{urine} + V_{water})$	0.33	1	1
pH	9.0	9.1	6.2
N_{total} (g/m^3)	1795	9200	8830
$NH_4^+ + NH_3$ (g N/m^3)	1691	8100	463
$NO_3^- + NO_2^-$ (g N/m^3)	0.06	0	–
P_{Gesamt} (g/m^3)	210	540	800 – 2000
CSB (g O_2/m^3)	–	10 000	–
K (g/m3)	875	2200	2737
Na (g/m^3)	982	2600	3450
Cl (g/m^3)	2500	3800	4970
Ca (g/m^3)	15.75	0	233
Mg (g/m^3)	1.63	0	119

Urine, a Special Liquid

Urine that is collected and stored for a prolonged period differs considerably from the original solution (Tab. 1). It develops a pungent odour of ammonia, and the pH increases from 6 to more than 9. Both of these changes are a result of the bacterial hydrolysis of urea, which produces ammonia and carbon dioxide. The chemical composition is also influenced by the amount of flushing water in the collection system.

Particularly striking are the high concentrations of nutrients in undiluted urine. Compared with normal wastewater, the concentrations of total nitrogen and total phosphate are about 200 and 100 times higher, respectively, and the chemical oxygen demand is approx. 30 times greater. If fresh and stored urine are compared, the transformations occurring during storage are clearly evident. The content of inorganic nitrogen (NH_4^+ + NH_3) and the pH are increased as a result of urea hydrolysis. This also leads to a reduction in the concentrations of calcium (Ca), magnesium (Mg) and phosphate, which are deposited as solids in the tank or pipes (see the article by Kai Udert on p. 11).

While scarcely any heavy metals are found in human urine, many medicines and hormones are excreted via the kidneys (see the article by Beate Escher on p. 23).

nitrogen under anaerobic conditions with the aid of nitrite. Both liquids may also be used to combat odours and corrosion in the sewer system.

Micropollutants Destroyed or Inactivated by Ozonation. The most reliable method of eliminating micropollutants has proved to be ozonation. Although the pollutants may not be completely broken down by this process, they are largely inactivated. If micropollutants are to be removed from a specific product, such as a fertilizer, nanofiltration or electrodialysis can also be used (for details see the article by Wouter Pronk on p. 20). Since it appears that not all micropollutants are degradable in bioreactors, combination with ozonation needs to be considered so as to ensure that the micropollutants are largely eliminated. In our studies, the substances propranolol (beta-blocker), ibuprofen (anti-inflammatory agent) and ethinyl estradiol (synthetic hormone) were poorly degraded, whereas the natural hormones estradiol and estrone were very effectively eliminated.

Nutrient Recovery Through Evaporation and Stripping. The composition of urine makes it a good multicomponent fertilizer. The nitrogen-phosphorus-potassium (NPK) ratio is approx. 100:6:25 (Tab. 1) or, using the standard fertilizer nomenclature, $N : P_2O_5 : K_2O$ = 0.9 : 0.12 : 0.26 (percentage by weight). There are various ways in which the nutrients can be further concentrated, or individual nutrients recovered:

► Volume reduction: this process facilitates storage, transport and dosing. Technically the most mature method is evaporation.

Tab. 2: Possible methods for urine treatment [1]. o = no effect, + = positive effect, ++ = strong effect, ? = effect possible, but not studied.

	Hygienization	Volume reduction	Stabilization	Nutrient recycling	Degradation/inactivation micropollutants	Separation nutrients – micropollutants	Nutrient elimination
Hygienization							
Storage	+	o	o	o	o	o	o
Stabilization							
Acidification	+	o	++	o	?	o	o
Sterile filtration	+	o	++	o	o	o	o
Nitrification	+	o	++	o	?	o	o
Nutrient recycling							
Volume reduction, e.g. Evaporation	+	++	+	++	o	o	o
Struvite precipitation	o	++	+	++ (esp. P)	o	++	o
Selective adsorption	o	+	o	++ (only N)	o	+	o
NH_3 stripping	o	+	o	++ (only N)	o	++	o
Nutrient elimination							
Anammox	+	o	++	o	?	+	++
Elimination of micopollutant							
Electrodialysis	++	+	+	+	o	+	o
Nanofiltration	++	o	+	o	o	++	o
Ozonation	+	o	+	o	++	o	o

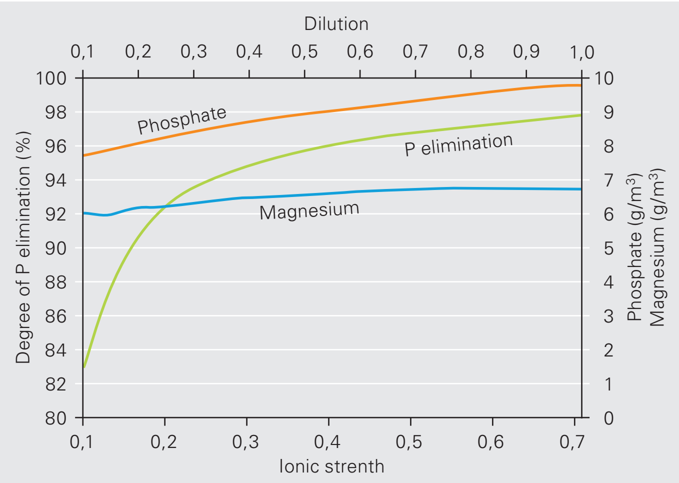

Fig. 1: The soluble phosphate and magnesium concentrations after struvite precipitation depend on the degree of dilution with flushing water (1 = undiluted, 0.1 = 10-fold dilution). Initial concentrations of nutrients in undiluted urine: phosphate = 440 g P/m^3; ammonium = 7850 g N/m^3. An equimolar quantity of magnesium chloride is added (based on phosphate).

This is also used on a small scale in space stations. In our tests carried out at 200 mbar and 78 °C with non-hydrolysed urine (see Box), it was a simple matter to reduce the volume by a factor of 10. In another method, known as partial freezing, urine is frozen to such an extent that one fraction remains liquid. This liquid phase contains the bulk of the nutrients, whereas the ice consists mainly of water.

► Stripping: ammonia is stripped out of the urine, e.g. by means of an air stream, producing an ammonia or ammonium sulphate solution. Both products can be used either as starting materials or as fertilizers.

Nutrient Recovery by Struvite Precipitation and Selective Adsorption. Struvite (i.e. magnesium ammonium phosphate, $MgNH_4PO_4$, or MAP) is a well-established slow-acting multicomponent fertilizer. Our laboratory studies showed that this compound can also be produced from urine. Struvite forms spontaneously as soon as magnesium is added to urine, e.g. in the form of magnesium oxide or magnesium chloride. The reaction is rapid and complete. The more urine is diluted with flushing water, the lower the yield of struvite (Fig. 1). To a certain extent, this can be offset by markedly increasing the quantity of magnesium added. With struvite precipitation, 96–98 % of the phosphorus content can be recovered from urine [5].

We also showed that the pharmaceuticals and hormones studied remained entirely in solution and were not detectable in the end product. No more than 20–40 % of any heavy metals contained in urine are precipitated with the struvite [6]. Struvite precipitation is thus a simple and effective method for recovering nutrients – free of pollutants – from wastewater streams.

Nutrients can also be obtained from urine by selective adsorption. An attractive option is the use of zeolite. If this mineral is added to urine, it adsorbs nitrogen and can subsequently be used as a nitrogen-containing soil conditioner.

Nutrient Elimination. If the ultimate goal of urine treatment is to improve water pollution control, the aim may be to remove nitrogen and phosphorus from urine without subsequently recycling these nutrients. Given the particular characteristics of urine, the anammox process described above can be used in addition to the methods usually applied for wastewater treatment.

Range of Processing Options Available for Urine Treatment. Numerous methods are suitable for the treatment of separately collected urine. Therefore, process engineering will certainly not be a limiting factor for the implementation of urine source separation in practice. At the same time, most of these methods are still at the laboratory stage. Practical experience is rare, and major gaps remain to be filled, especially in the development of reliable small-scale processing units for decentralized use.

The variety of possible urine treatment methods shows that source control measures such as urine separation, provide increased flexibility for wastewater management. The foundations have been laid for further development, and the time has now come for the transition to practical application. ○○○

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