New Aspects for Wastewater Treatment after Urine Separation

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Abstract
The development and implementation of alternatives to conventional wastewater disposal solutions is becoming increasingly essential both for economical and ecological reasons. Strategies of separate flow treatment and recycling must be promoted consequently also on the wastewater sector.
Separation of urine gives a multitude of new aspects and approaches for the treatment of wastewater. The holdback of urine enables construction of smaller and easy to run wastewater treatment plants and allows for the production of sludge with a rather high quality (less endocrinic disruptors). This is a very interesting aspect for countries where wastewater treatment plants and infrastructure has to be built up. The aspect could also be of interest in countries for plants running on their capacity where additional people have to be connected.
Another aspect is to consider urine not as a pollutant but as a useful resource. And if endocrinic disruptors will cause any problems separated urine will allow for efficient destruction of these substances and preserve nature and groundwater.

INTRODUCTION
It is adequately known meanwhile that the supply with sufficient water of sufficient quality for human needs and agricultural food production, and on the other hand the hygienic disposal of wastewater are serious problems for a great part of mankind. Every day a high number of people, many of them children, die from infections caused by polluted water.

In order to provide a future-proof solution to this situation and for the people concerned, a regular wastewater treatment needs to be established, in addition to the supply of hygienic drinking water, in order to prevent further pollution of surface waters and groundwater and secure the high quality of drinking water.
In the countries affected by such problems also the availability of nutrients for agricultural food production is frequently limited or involves relatively high costs. This adds another aspect to reuse of clarified wastewater for irrigation and consequential reuse of nutrients contained. But this aspect is frequently disregarded in wastewater solutions for industrialised countries.

The solutions and concepts developed in industrialised countries over many decades could now be reapplied in countries that still do not have wastewater treatment solutions. However, adaption of the technology and clarification requirements to the specific situation is imperative, as for example Libhaber (2004), World Bank chief engineer, said: ”In most developing countries, wastewater treatment and reuse standards are inspired by standards of industrialized countries, mainly the USA and EU, without taking into account financing and construction time issues. These standards usually prescribe an effluent of such quality that secondary treatment or higher is required to produce it, irrespective of the absorption capacity of the receiving body (i.e., the capacity of the receiving body is not taken into account in the standard setting process). Since the costs of applying these standards are high, usually beyond reach in developing countries, the overly stringent effluent standards induce a strategy of "No Action" with devastating public health and environmental impacts".

These statements lead to the conclusion that wastewater treatment must fulfil also the criteria of sustainability in terms of economic feasibility and social compatibility, in addition to legal and adapted requirements for environmental protection. Obviously, future wastewater treatment will have to further mature for the still outstanding solutions in order to provide for the development of solutions, within the limited time and with the limited funds available, which are best compatible for all requirements. "The population growth, which frequently relativises the improvements achieved, is only one of the difficulties in achieving the development goals. The worldwide increasing urbanisation increases the pressure on water resources. Intelligent solutions must be developed in order to nevertheless guarantee a sustainable water management. In 35 years, two third of the world population will live in urban areas. We are wasting water and contaminating water through agriculture, industries, mining and trade as water is too often a low cost factor", said Trittin (2005).

But even in Germany, where the rate of connection of the population to wastewater treatment plants is very high already, new requirements arise from the ever-present discussions about our water and energy resources concerning the right choice of a future wastewater strategy. Such requirements are (modified after Wallbaum (2005)):

- Need of renovation of existing infrastructures, such as sewers
- Need of renovation of buildings; refurbishment of old buildings to today's sanitary standards combined with improved heat insulation and recovery of heat from greywater
- New requirements on wastewater treatment due to for example endocrine substances, medicine residues and CO2 emission
- Limitedness of important resources, such as phosphate (Gethke e.t al. (2005)), potassium and fossil fuels
- Need of adaption to the demographic population change
- Adaption to the climatic change
- Implementation of the polluter-pays-principle
- The global market requires innovative infrastructure concepts, which however need to be shown also in the own country in order to have export chances.

Some of the presented discussion points, such as limitedness of resources and part of the undesired organic trace substances, put today's concepts of wastewater treatment into question, visionary thinking, since the problems result only from the urine, which is at present still part of the general wastewater flow.
The possible effects of urine separation from the wastewater flow are reviewed and discussed in the following also under the aspect of sustainability.

URINE SEPARATION

The urine contained in domestic wastewater adds up to only approx. 1%, with daily amounts of produced urine varying between 1.0 and 1.5 litres. For separation into individual substance flows dry toilets, vacuum toilets, separation toilets (NoMix toilets) or waterless urinals can be used. In waterless urinals, in contrast to conventional urinals, the urine is discharged into the sewer without addition of flush water, which saves 2-3 litres clean drinking water per toilet use. Contrary to conventional urinals, which use the conventional water siphon to prevent the rising of sewer gases,

waterless urinals use oily sealing liquids, rubber membranes or a solenoid seal, depending on the individual urinal manufacturer.
The following table shows the distribution of nitrogen and phosphorus in urine and faeces. The data are based on Vinneras (2004), Sweden.

Table 1: Distribution of nitrogen and phosphorus in human excretions

	Unit	Urine	Faeces	Toilet paper	Black water	Urine [%]	Faeces [%]
M	kg/PE*a	550	51	8.9	610	90	10
M_{dry}	kg/PE*a	21	11	8.5	40.5	52	48
N	g/PE*a	4000	550		4550	88	12
P	g/PE*a	365	183		548	67	33

On the basis of these values, consequences are described in the following which result from retention of urine from the residual wastewater flow. The discussion comprises two possible approaches: Mechanical-chemical treatment and comparable conventional wastewater treatment.

Impact of urine separation on wastewater composition

The following table shows the load and concentration of normal wastewater as specified in work sheet DWA A 131 compared to applications with urine separation.

		normal compositi on	composition without urine	normal concentr. mg/l	concentr. without urine mg/l
Waterr	l/PE d	130	110		
BOD	g/PE d	60	60	462	545
COD	g/PE d	120	105.6	923	960
AS	g/PE d	70	70	538	636
N	g/PE d	11	1.331	85	12
P	g/PE d	1,8	0.60	14	5

The results show that with urine separation nitrogen can be reduced to approx. 12 mg/l and phosphorus to approx. 5 mg/l.

MECHANICAL AND CHEMICAL TREATMENT

If located directly next to the receiving water body, it is reasonable for newly industrialising and developing countries, but also for thinly populated areas in general, to treat the wastewater in river-and-sea outfalls directly at their source of production, using an especially developed fine screen for separation of solids, which have hardly had the chance to dissolve due to relatively short flow ways.

Mechanical preliminary screening can be a quick and cost-effective solution for removal of undissolved material from wastewater and is in most cased applied therefore as the first treatment step with the purpose to eliminate particular matter contained within water to the greatest possible extent. Additional treatment steps, using chemical precipitants and flocculants, help to further improve the wastewater quality and adapt it to specific requirements.
Such a concept is presented in the following diagram:

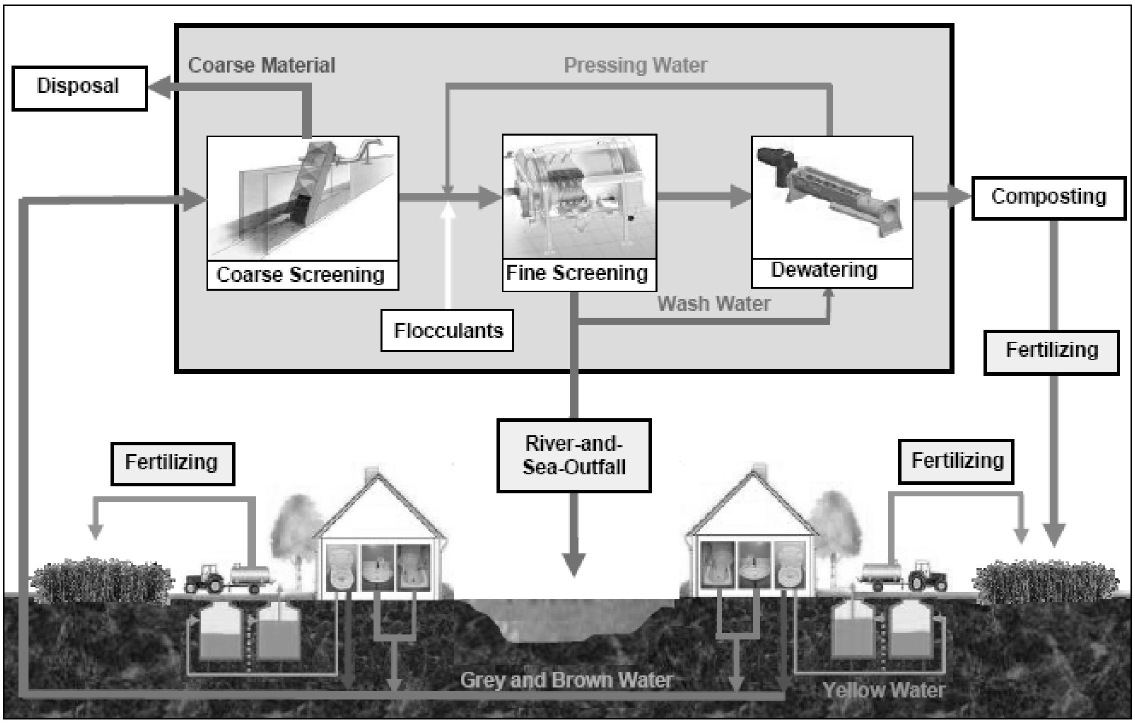


Fig. 1 Concept of urine separation in combination of river- and sea-outfall

This method of treatment mechanically eliminates high concentrations of solids and thus oxygen consuming substances. The separation of the COD contained within in the wastewater was tested both without and with the addition of chemicals from a wastewater treatment plant. The tests were carried out under real conditions over a period of several months. The results of Huber et. al. (2004) are presented in fig.2.

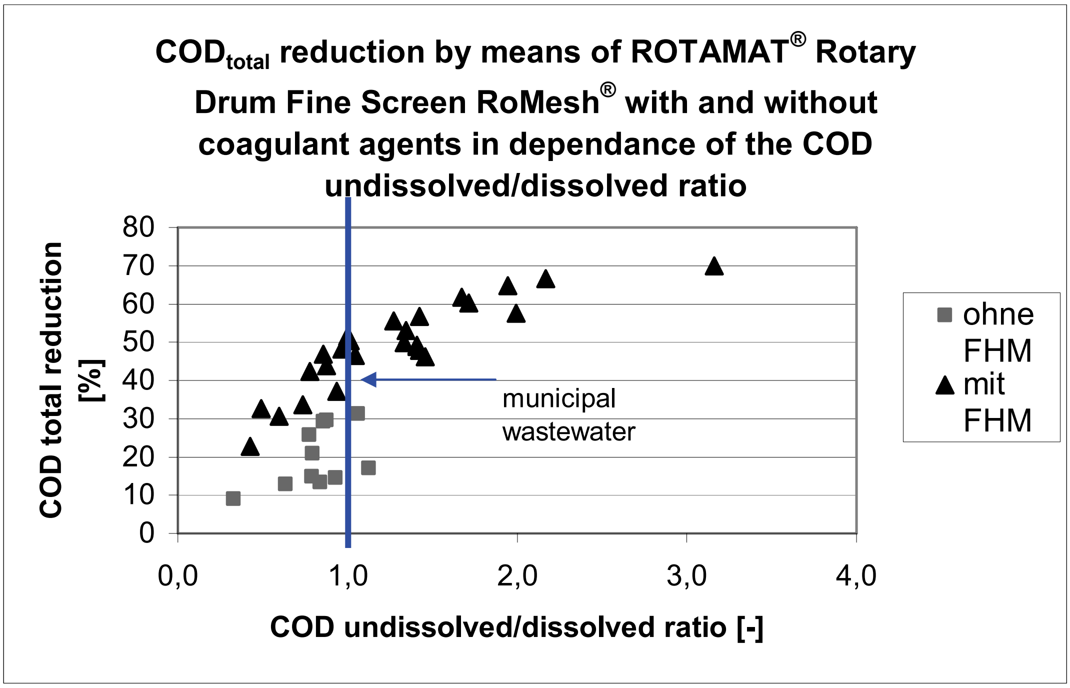


Fig. 2 CODtotal reduction by means of ROTAMAT® Rotary Drum Screen RoMesh® with and without coagulant agents in dependence of the COD undissolved/dissolved ratio

As can be seen in fig.2, a COD reduction of up to 30% is possible with mechanical treatment alone. If mechanical screening is combined with precipitants and flocculants (mechanical-chemical treatment MeChem), a COD reduction of even up to 70% can be achieved. If this combined treatment is applied for the wastewater separated from urine, the wastewater effluent can be calculated as specified in the following table. This effluent quality, which is achievable by simple means, is already a relatively high quality for introduction into a receiving water body.

		MeChem
COD	mg/l	288
AS	mg/l	32
N	mg/l	12
P	mg/l	1

BIOLOGICAL TREATMENT

When taking as a basis a conventional biological treatment plant for 100,000 PE with preliminary treatment according to design instructions A131, the resulting calculation size of the biological wastewater treatment stage with nitrification and denitrification for normal wastewater composition is approx. 19,400 m³. The oxygen demand is approx. 460 kg/h and approx. 7800 kg sludge are produced per day. On the basis of this design approach an outlet concentration of approx. 10 mg/l nitrogen can be achieved.

If the urine is not any more contained in the wastewater, the total nitrogen in the inlet to the wastewater treatment plant is only 12 mg/l. Since also nitrogen and phosphorus are required during the decomposition of carbon compounds, the effluent value for nitrogen will lie in the same range as with regular nitrification and denitrification, but the wastewater treatment plant can be planned with only carbon reduction alone. As a result, the required reaction volume for the aeration tank can be reduced to approx. 5.500m³, which means theoretical savings of approx. 70%. Concerning the investment cost for aeration tanks (Günthert, (2001)) this leads to costsavings of 2.5 millions of Euro. The required oxygen input is in this case reduced by approx. 40% to 260 kg/h. The daily produced sludge volume of approx. 8000 kg/d lies within a comparable range.

A comparison of the different effects on the above discussed cases is presented in the following figure 3.

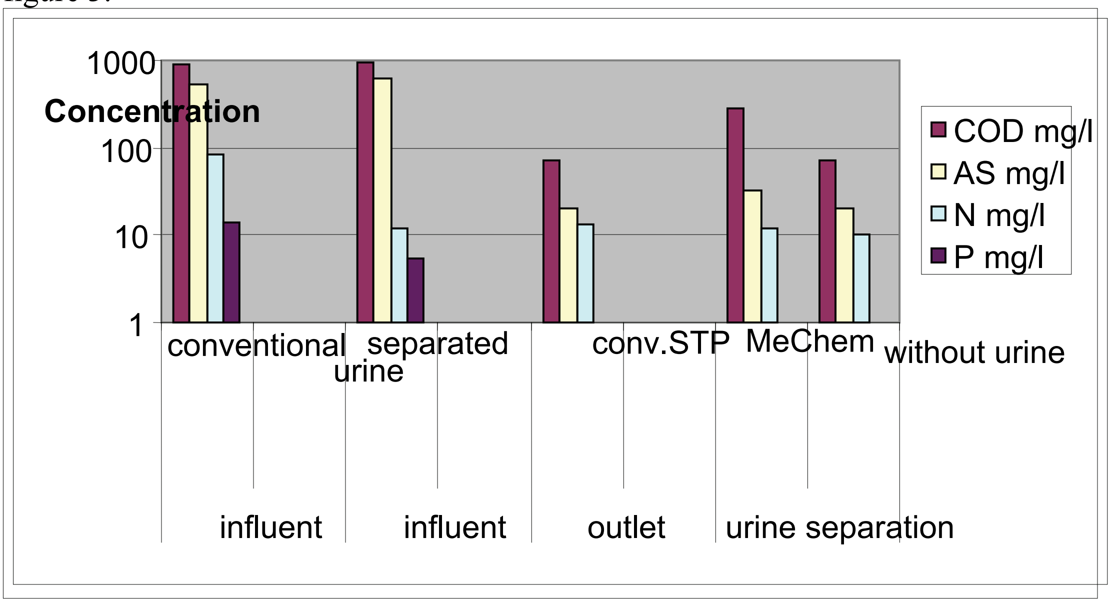


Fig. 3 Results for different effects on treatment without and with urine separation

THE DISCUSSION OF SUSTAINABILITY

In addition to the reduced tank volume, which directly results in reduced investment costs, further interesting aspects arise for wastewater treatment concepts without urine.

The plant design and control could be relatively simple, which would be to the benefit of developing and emerging countries as the knowledge how to operate sewage treatment plants must be assumed to be low in such countries. In addition, the sewage sludge quality achieved is comparatively high due to the high retention of endocrine substances and medicine residues from the residual wastewater flow, which may be advantageous for the return of treated water into agricultural reuse applications. Furthermore, due to the low oxygen consumption, the energy costs can be reduced significantly.

Interesting aspects, however, arise when discussing the energy savings. The reduction of the required oxygen input of approx. 200 kg/h results in savings of nearly 785,000 kWh with an average oxygen input of 2.2 kg O2/kWh for aeration equipment, which corresponds to savings of 117,000 € on a cost basis of 0.15 €/kWh per year.

Under the aspect of sustainability and the climatic situation this energy savings correspond to an annual reduction of a CO2 production of approx. 235,000 kg.

Particularly with regard to CO2 savings from fossil energy sources enormous efforts are being taken in Germany at present in order to reduce the dependence on coal and oil. That is why the new law for renewable energies (EEG) was enforced, which regulates the electricity compensation rates for a period of 20 years. In the following, a comparison with photovoltaics is provided. For the production of 785,000 kWh solar energy in Germany, approx. 800 kW installed capacity is required according to state-of-the-art technology, which results in investment costs of 3.7 million Euro. Related to the contractual period of 20 years according to the law for renewable energies (EEG) the legislator is prepared to have the annual production of 785,000 kWh by means of photovoltaic plants compensated at the amount of approx. 6.000.000 €.

The separated urine, in dependence of organic trace elements and the applied treatment technologies, can offer the potential to provide for value creation due to the contained nutrients. The height of this potential can be evaluated by comparison with the market value of mineral fertilisers. The internet finds a selling price of 39 € per 100 kg for ammonium nitrate (27% N) and 39.50 € per 100 kg for phosphate fertiliser with a rate of 18%. When taking as a basis again the annual amount of urine produced by 100,000 PE and calculating the nutrients content according to the urine composition, this calculation results in approx.400 tons nitrogen and 36.5 tons phosphorus with a market value of approx. 570.000 € for nitrogen and 80,000 € for phosphorus. How far it is possible to make use of this potential depends on the concepts and technical processes, which are partly in the developing phase already, and on the efficiency of such concepts and processes.

RECOVERY OF NUTRIENTS FROM URINE

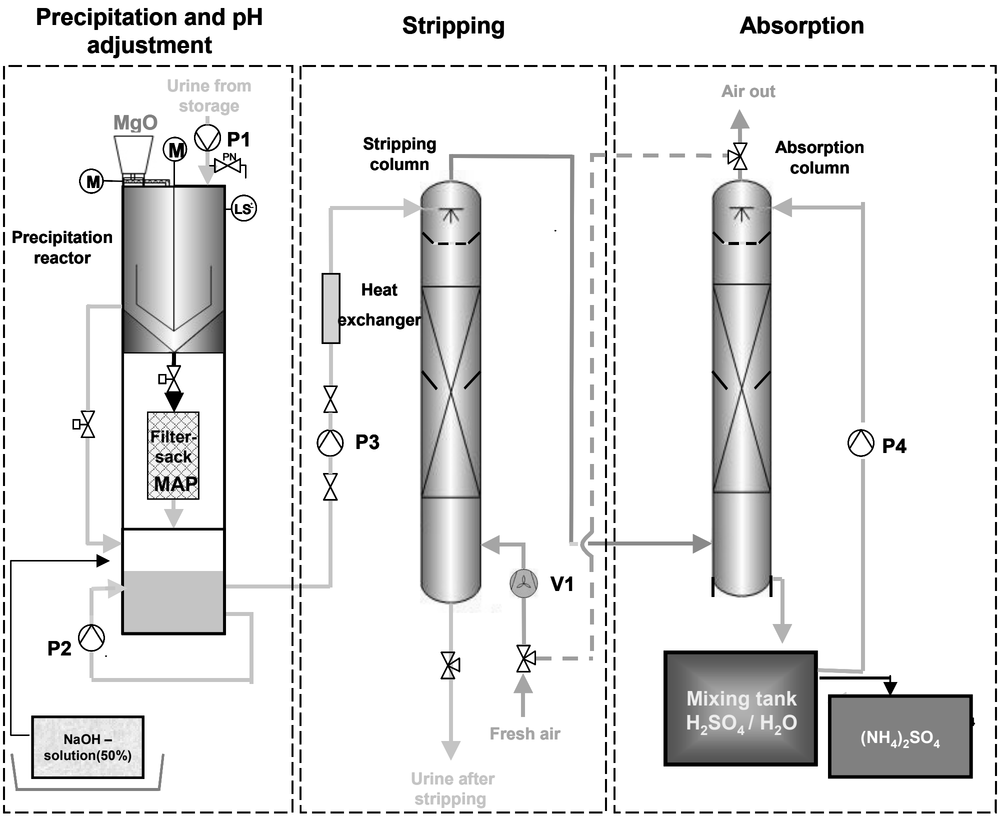
Within the scope of the Novaquatis research project of EAWAG Switzerland and the technical college at Basel, tests according to Wolfersdorf (2004) were carried out for evaporation of human urine. For prevention of urea hydrolysis and consequently a loss of nitrogen through evaporation of ammoniac during the heating process, acidification of the urine is required prior to passing the urine into the pipeline that leads to the urine storage tank. The best cristallisation result was achieved by acidification with acetic acid.

In the reverse osmosis process the water contained in the urine is with high pressure forced through a semi-permeable membrane. In addition to viruses and bacteria even ions can be retained when selecting an adequate membrane type.

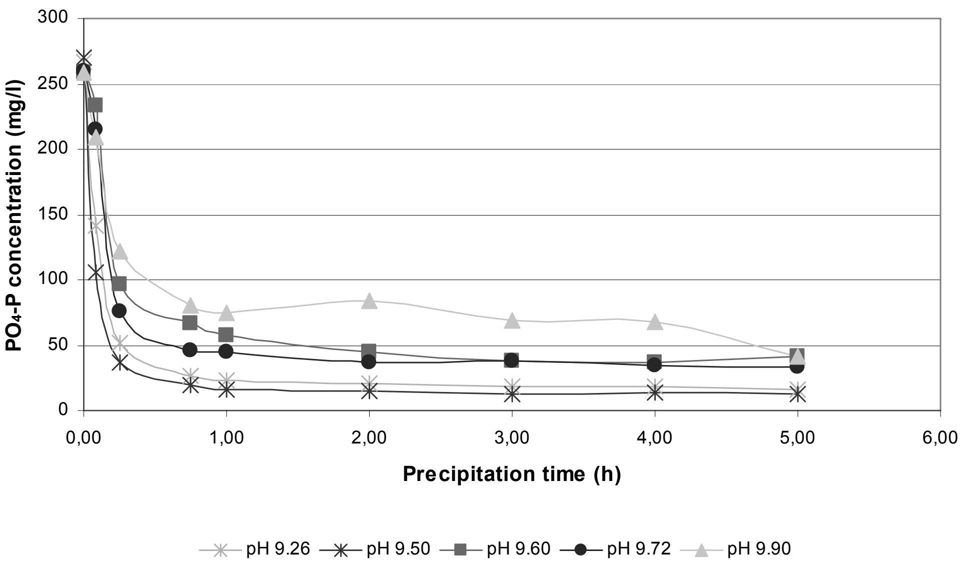
The application of reverse osmosis for urine concentration involves the problem of relatively high investment costs, membrane susceptibility to clogging and a high energy demand. According to Maurer (2005) an energy of 9 kWh/m3 is required for the fivefold concentration of urine.

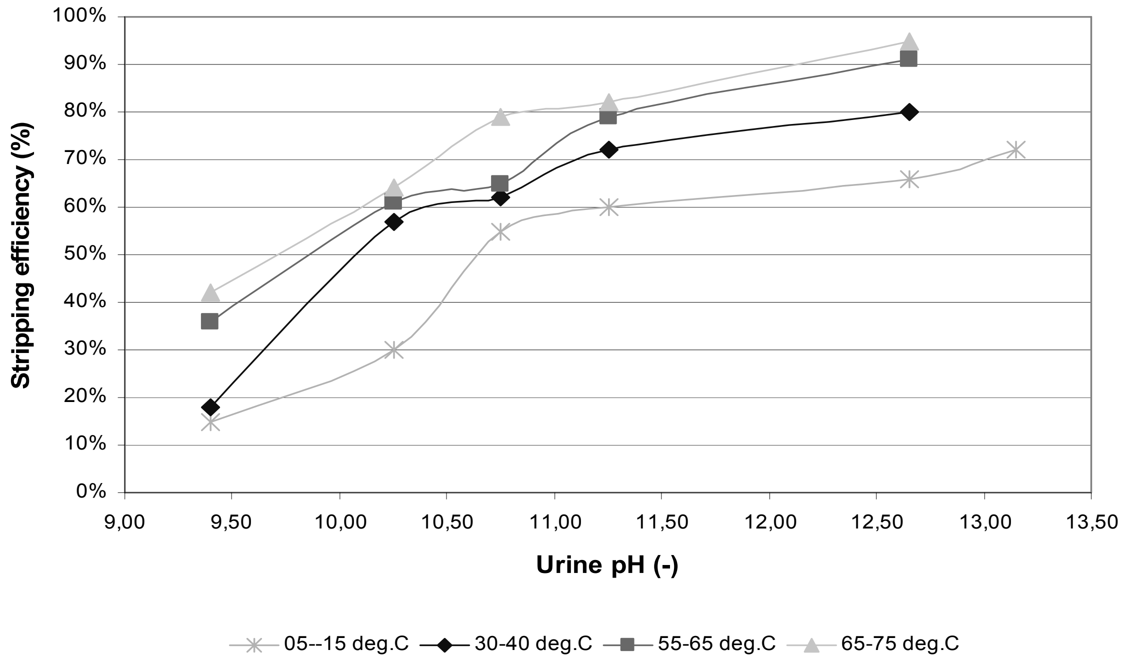
MAP precipitation for nitrogen elimination: MAP is produced when ammonium, phosphate and magnesium ions react in a stoichiometric ratio of 1:1:1. Due to the conditions prevailing in the urine the molar ammonium concentration is approx. 100 times higher than that of phosphate. For the separation of the total ammonium contained within urine in the form of MAP, the addition of nearly 0.3 mol/l or 28.5 l phosphate would be required. Tests carried out by X.L. Li and Q.L Zhao (2003) with waste dump leakage water achieved a NH4-N elimination in excess of 90% through addition of Na2(HP04) and use of MgC12 with minimum pH 9. The initial NH4-N concentration, however, was only 2,750mg/l.
The great advantage of this method is certainly the low investment sum for the precipitation reactor. The high operating costs for the huge amounts of phosphate salt will probably impair the efficiency of this method significantly.
Tests with urine carried out by Sreeramachandran (2006) delivered the following result: Results on laboratory experiments conducted for simultaneous precipitation P indicate that a combination of Na2HPO4.12H2O+MgCl2.6H2O or a combination of 2 4 2 2 2 K HPO .3H O +MgCl .6H O at a Mg:N:P ratio of 1.25:1:1 is most recovery of above 80% compared to other combinations being tested.

The Hans Huber AG has developed a multi-stage process, which is presently in the optimisation phase. The process flow diagram is presented in the below figure. It is basically possible to apply precipitation alone.



The results of extensive tests carried out by Sreeramachandran (2006) showed a great potential for MAP precipitation or application of the total process respectively.





CONCLUSION

Separation of urine from the wastewater flow is the beginning of a discussion comparable to that about the introduction of waste separation many years ago. As shown, it has many potentials that should not be left unused. The possibility to achieve a high effluent quality in river-and-sea outfall applications combined with the relatively cost-effective mechanical and chemical treatment meets in particular the requirement to offer easy-to-realise and affordable solutions. Moreover, the design of biological systems is much simpler, resulting in significantly reduced construction volumes and energy consumption. But a reduced nitrogen load also brings relief when extending existing wastewater treatment plants. Compared to other technical options for CO2 reduction, it could be shown that there is a high political readiness to introduce the photovoltaic technology despite comparably high financial requirements. Incentives should therefore be offered also for the separation of urine from water, not only under the aspect of saving energy but also under the aspect of preventing trace substances from passing into the environment, providing the potential of easier destruction of these trace substances being present in a concentrated form, and using the potential of nutrients contained within urine.

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