Continuous versus Batch Contacting for Nutrient Removal from Human Urine upon Processing with Clinoptilolite-II: An Appraisal of Possible System Dimensions and Costs

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Abstract
Human urine can be used as fertilizer due to its rich nutrient content. Ion exchange/adsorption is one successful method for recovery of nitrogen and phosphorus from human urine using an indirect route. Although this process can be applied in batch or continuous modes, majority of the work reported employs batch operation. This paper aims to present a comparison of the two modes focusing on system dimensions and costs. The results of the study showed that column dimensions including column diameter, bed/column heights for continuous system are smaller than their batch counterparts. The investment cost was calculated as an average of 2500 USD for a household accommodating 4 people, including two urine diverting toilets, two 100 L urine storage tank, an ion exchange/adsorption column, a pump and piping for both operating modes. Operating costs were calculated taking the cost of clinoptilolite, electricity and chemicals into consideration, which had given 6-12 USD/100 L urine for the batch and 3-3.5 USD/100 L urine for continuous systems. In conclusion, continuous mode of operation for nutrient removal from human urine through processing with clinoptilolite yielded smaller system dimensions and lower operation costs.

Keywords
Nutrient removal/recovery; clinoptilolite; ion exchange/adsorption; column dimension; batch/continuous operation; investment and operational cost

INTRODUCTION

Containing over 80% of nitrogen and over 50% of phosphorus in conventional domestic wastewater, human urine is a potential and renewable source of fertilizers. Human urine can be applied onto soil as fertilizer either directly or indirectly. Storage is recommended for hygienic safety prior to direct application (Hoglund, 2001; WHO 2006), mostly accompanied by dilution to alleviate salinity hazard, if applicable (Beler Baykal and Bayram, 2005; Beler Baykal et al., 2011; Kocaturk and Beler Baykal, 2012). Processing of urine prior to indirect application is necessary. The most common processes used are struvite precipitation, stripping/absorption, and ion exchange/ adsorption. A phosphorus-rich fertilizer is produced in struvite precipitation and a nitrogen fertilizer through stripping/absorption (Beler Baykal and Dogan, 2016). Examples of struvite precipitation in literature include Kabdasli et al. (2006), Wilsenach et al. (2007), Ganrot et al. (2007, 2008), Tilley et al. (2008), Dogan (2015) and stripping/absorption Basakcilardan-Kabakci et al. (2006), Dogan (2015).

Although ion exchange/adsorption is used in some pieces of work for removal of phosphorus only as exemplified by O'Neal and Boyer (2013, 2015), it is the successful method of recovering both nitrogen and phosphorus simultaneously for further use when the natural zeolite clinoptilolite is employed as the ion exchanger/adsorbent. In this case, both nitrogen and phosphorus in urine are transferred onto clinoptilolite, to be subsequently made available to plants through desorption upon contact with water either through irrigation or precipitation (Beler Baykal et al., 2004, 2009, 2011; Kocaturk and Beler Baykal, 2012; Allar and Beler Baykal, 2013, 2015).

Successful results were obtained with nutrient enriched clinoptilolite (exhausted clinoptilolite) produced from indirect use of human urine through the ion exchange/adsorption process. When this product was applied onto different plants, equivalent or higher yields as compared to synthetic fertilizers were achieved (Beler Baykal et al., 2011; Kocaturk and Beler Baykal, 2012; Allar, 2015). In a previous publication by Allar and Beler Baykal (2016), it was reported that the amount of exhausted clinoptilolite produced as fertilizer from urine coming from a housing site was self-sufficient and without excess for that small community and processing could be done at a reasonable cost.

A search into the existing literature on the subject matter reveals that most of the papers refer to batch-wise contacting for loading nitrogen and phosphorus purpose onto clinoptilolite (Beler Baykal et al., 2004, 2009, 2011; Kocaturk and Beler Baykal, 2012; Allar and Beler Baykal, 2013, 2015), although there exists the option of continuous operation. In another paper by Allar Emek and Beler Baykal (2016), it was demonstrated that as opposed to the advantage of batch contact from the perspective of higher removal efficiencies and lower concentrations remaining in the liquid residue, continuous operation may be preferred because of faster exhaustion/operation times and higher surface concentrations meaning unit mass of clinoptilolite would remove higher amounts of nutrients from urine. Considering these features of the two modes of contact and the impact of costs on final process selection, the aim of this paper was set as an effort of comparison between the two different modes of contact with specific emphasis on the determination of column dimensions and cost estimates. An analysis of the production cost using the suggested route, and a comparison with current market prices is also included together with an estimate of investment costs.

MATERIAL AND METHODS

The analysis and calculations presented in this paper are based on the experimental data presented by Allar Emek and Beler Baykal (2016). In those experiments, source separated human urine stored for at least two months was used to assure that hydrolysis of urea was completed. This was done to provide nitrogen in the form of ammonium to ensure that nitrogen is in the ionic form to allow highest possible removal through ion exchange. The clinoptilolite, a natural zeolite which is also used as soil conditioner, employed in this work was from Gordes region of Turkey. It was preconditioned with sodium chloride to produce the sodium form which is known to be the form with highest surface capacity. The particle size used was 1-2 mm and the bulk density calculated from column experiments was 0.6327 g/cm^3.

Initial ammonium loading for batch systems (Beler Baykal et al., 2009) and empty bed contact time for continuous systems (Droste, 1997; Inan, 2001) are the main parameters under these conditions. Therefore, various initial loadings between 10-40 mg ammonium/g clinoptilolite and contact times between 30-120 minutes were tested by Allar Emek and Beler Baykal (2016).

For the analysis and calculations in this work, the typical concentration of urine was taken as 7500 mg NH_4/L based on the range 5700-10620 mg/L, from data generated by this research group using numerous urine samples (Beler Baykal and Bayram, 2005; Beler Baykal et al., 2009, 2011; Kocaturk and Beler Baykal, 2012; Allar and Beler Baykal, 2015). As an average, one person is expected to excrete 1.5 L urine/day. In this work, it was postulated that 1 L of this could separately be collected for further processing.

All calculations in this work were based upon the amount of nitrogen recovered. Surface capacities of clinoptilolite were taken as 7.2-19.4 mg NH_4-N/g clinoptilolite for batch and 26-30 mg NH_4-N/g clinoptilolite for continuous systems as reported by Allar Emek and Beler Baykal (2016). These values were used to calculate the total zeolite requirement, column dimensions including volume, diameter and bed/column heights, and costs. Values were all reported taking unit urine volume and population as basis. Since 1 L/day was taken as the amount to be collected from one person for processing, urine volume and population values coincide.

Clinoptilolite requirement was calculated from

i) the mass of nutrients excreted by one person, using ammonium concentration in urine and urine volume, and
ii) each initial ammonium loading adopted for the batch mode, or from actual surface ammonium concentrations observed at each contact time in the continuous mode.

Bed volumes were determined from clinoptilolite requirement and the bulk density of clinoptilolite. Possible combinations of column diameters and bed heights were calculated using the bed volumes and the minimum ratio of ¼ for diameter/bed height. Finally, column heights were determined as 1.5 times that of bed heights.

Investment cost was calculated taking two urine diverting toilets per household serving four people, piping, two storage tanks, clinoptilolite column and pump into consideration. Operational costs for processing of 100 L of urine were calculated taking expenditures for clinoptilolite, power and chemicals into account.

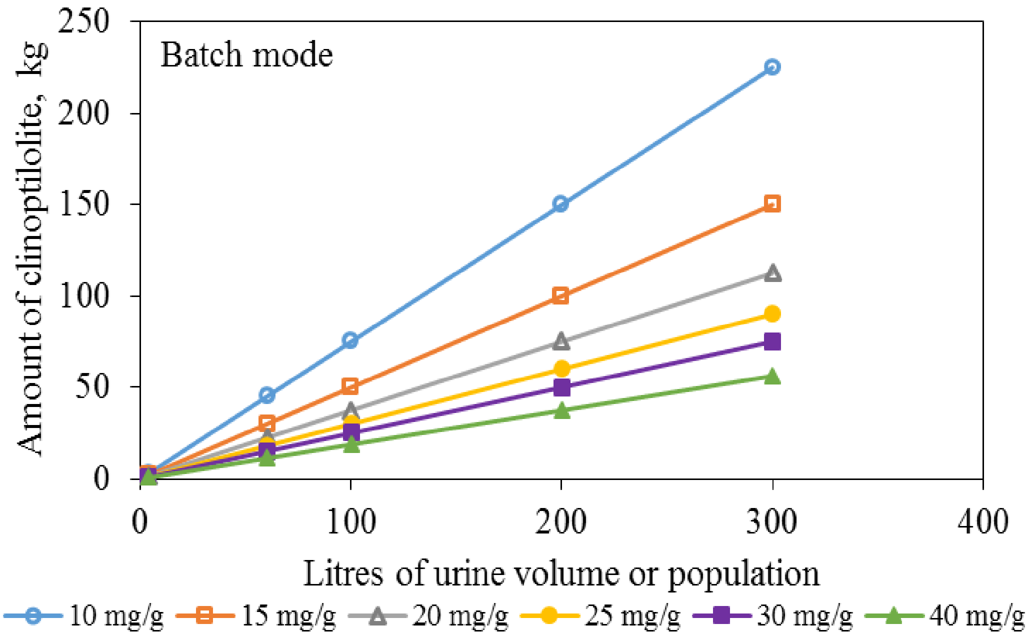
RESULTS AND DISCUSSION

Taking into account, the advantages/disadvantages of batch versus continuous modes of contact (Allar Emek and Beler Baykal, 2016) and the impact of costs on final process selection, this paper was intended as an effort to compare the two different modes of contact focusing on column dimensions as significant determinants of cost together with cost estimates.

First, clinoptilolite requirement under different types of operation were determined. The results of calculations are shown in Figure 1 for batch and continuous loading modes. As can be seen from the figure, and as can also be expected from the surface capacities used for the calculations, clinoptilolite requirement was higher for batch operation as compared to the continuous mode. Clinoptilolite requirement ranged between 20-75 kg for batch operation as opposed to 20-25 kg for continuous operation for 100 L of urine, reaching a threefold difference in favor of continuous operation.

Bed volumes calculated using the bulk density together with column heights/diameters as dimensions are shown in Figure 2 for batch and continuous loading modes. The higher clinoptilolite requirement observed for batch operation as compared to the continuous mode also reflected onto bed volumes, column heights and diameters as larger dimensions, as expected. The calculated bed volumes were 30-120 L for batch and 30-40 L for continuous operation.

Using these bed volumes calculated, possible configurations of columns in terms of column diameters and bed/column heights were also determined. Column diameters were 22-32 cm, bed heights were in the band of 80-148 cm, and column heights 120-222 cm for batch systems as opposed to 22 cm, 82-105 cm and 123-158 cm in their continuous counterparts for 100 L urine, indicating the advantage of continuous operation.



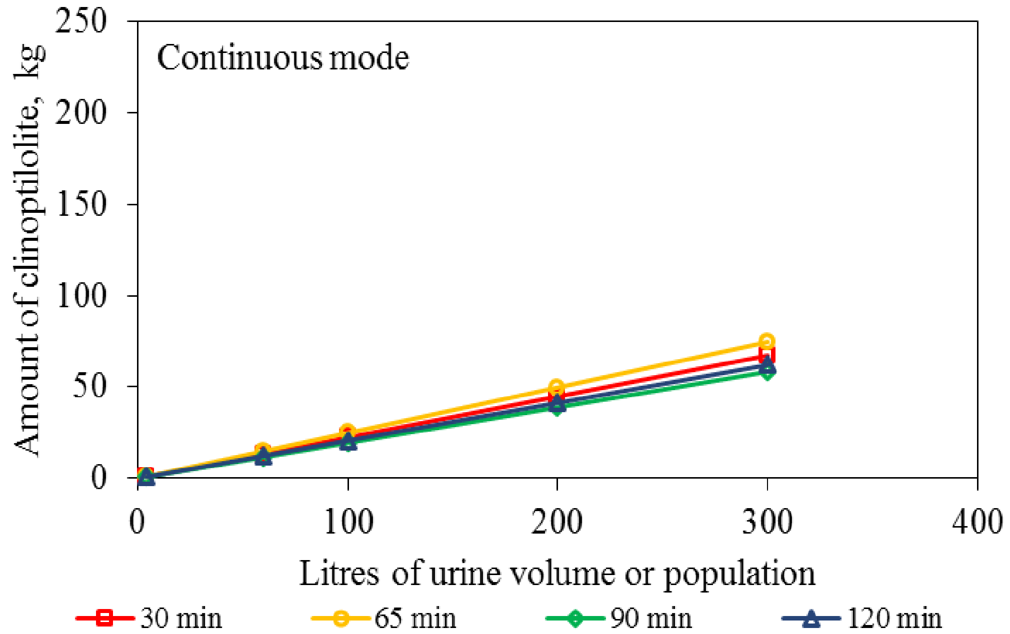


Figure 1. Clinoptilolite requirement for batch and continuous operation

Through a survey of Figures 1 and 2, overall, it may be observed that contact time based variations in continuous operation is less pronounced as compared to large variations in initial loading based batch operation both from the perspective of the amount of clinoptilolite required and for dimensions including column volume, height and diameter.

Investment cost was calculated as 2500 USD per household which was assumed to accommodate 4 people, including two urine diverting toilets, two 100 L urine tanks, one for collection and one for storage, ion exchange/adsorption column, pump and piping for both operating modes. The breakdown of prices are given in Table 1.

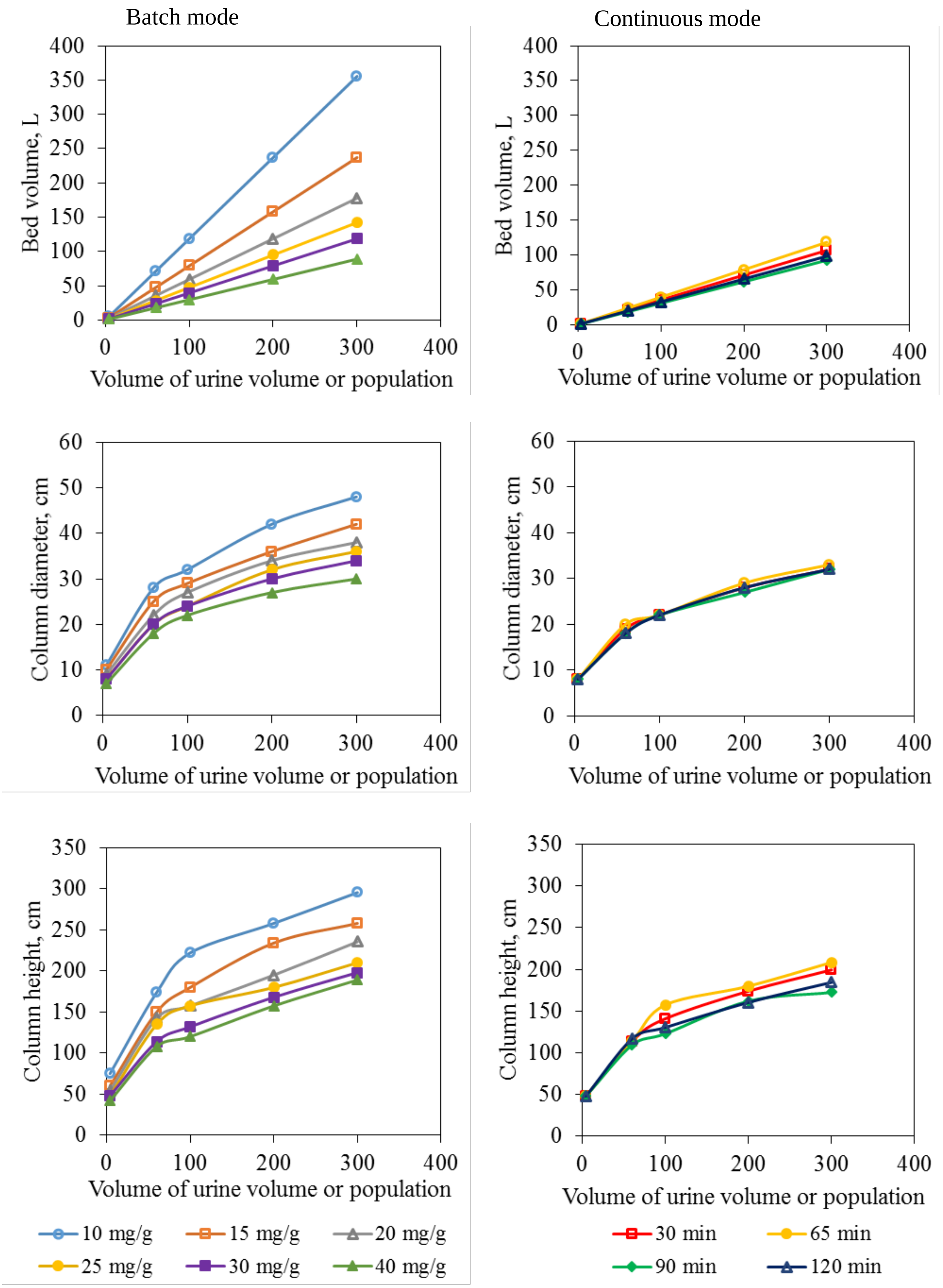


Figure 2. Column dimensions for batch and continuous operation

Table 1. Investment cost for one housing unit

	$
Urine diverting toilet	1745
Piping	30
Tanks	40
Column	514
Pump	171
Total cost	2500

Operating costs were calculated taking the cost of clinoptilolite, electricity and chemicals into account, which had given 6-12 USD/100 L urine for batch and 3-3.5 USD/100 L urine for continuous systems as shown in Table 2 and Figure 3. Similar to clinoptilolite requirement, variability in the operation cost is more obvious for batch operation as compared to the continuous one. In addition to the amount of clinoptilolite to be used, costs were closely dependent upon operation times, which were two days for the batch system and maximum 10 hours for the continuous one, which in turn had implications on the cost of electricity.

Based upon the foregoing discussion, 1 kg of nitrogen produced via the suggested route to be used as fertilizer is estimated to cost 5.6 USD as an average. A survey of market prices for composite fertilizers reveals that the expected cost for 1 kg of nitrogen to be between 2-11 USD. A comparison with this value shows that the production cost for nutrient loaded clinoptilolite is reasonable, especially when combined with the fact that clinoptilolite itself is also widely applied for agricultural/landscape purposes as a commonly used soil conditioner. Additionally, nutrient enriched clinoptilolite provides phosphorus in addition to nitrogen which was taken as the basis of this analysis.

Table 2. Operating costs for batch and continuous mode

		Clinoptilolite cost, $	Electricity cost, $	Chemical cost, $	Total cost, $
Batch mode	10 mg/g	7.50	3.88	0.73	12.1
	15 mg/g	5.00			9.6
	20 mg/g	3.75			8.4
	25 mg/g	3.00			7.6
	30 mg/g	2.50			7.1
	40 mg/g	1.88			6.5
	50 mg/g	1.50			6.1
Continuous mode	30 min	2.25	0.11	0.73	3.1
	65 min	2.49	0.27		3.5
	90 min	1.95	0.43		3.1
	120 min	2.07	0.53		3.3

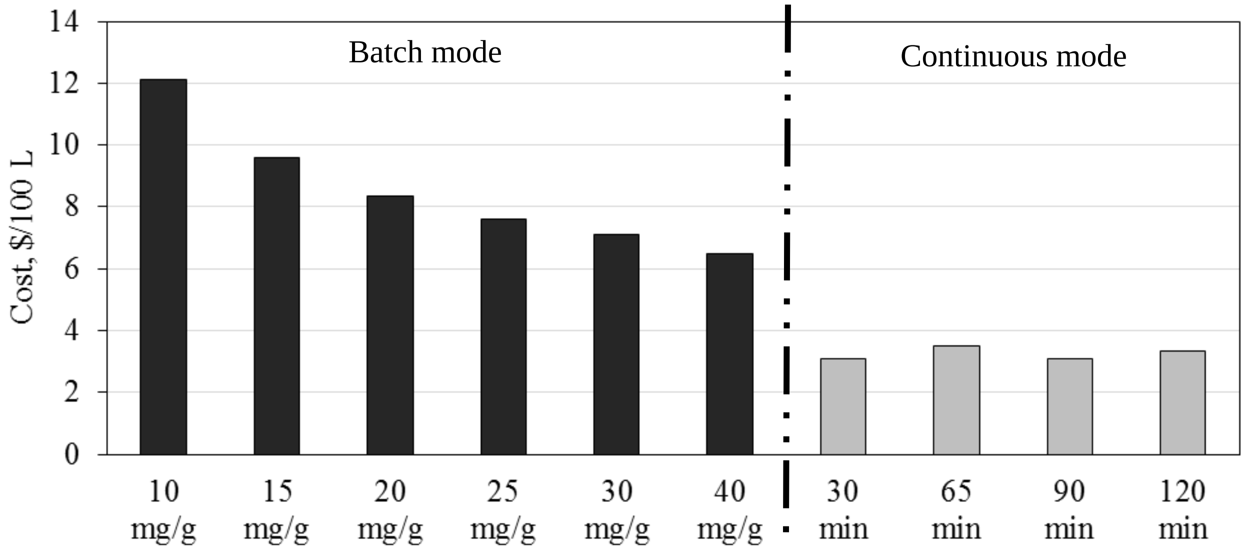


Figure 3. Operation costs for various batch and continuous operation modes

CONCLUSIONS

Nitrogen and phosphorus in source separated human urine to be used further as fertilizer is a significant renewable source which should not be wasted. Hence, recovery of nutrients from urine is a promising practice from the perspective of sustainability. As opposed to phosphorus recovery only through struvite precipitation and nitrogen recovery only from stripping/absorption processes, processing urine with the natural zeolite clinoptilolite via ion exchange/adsorption leads to the recovery of both nitrogen and phosphorus simultaneously in one single process. Contacting in ion exchange/adsorption can be provided either through batch-wise or continuous modes. Due to higher surface capacities achieved with continuous systems, clinoptilolite requirement and column dimensions in such systems are smaller as compared to batch operation. This leads to lower operating costs in continuous mode making it preferable over batch systems. Production cost of fertilizers via the suggested route seems reasonable.

REFERENCES

Allar, A.D. 2015 Alternatives for indirect use of urine as fertilizer through processing with clinoptilolite. *PhD Thesis*, Istanbul Technical University, Istanbul, Turkey (in Turkish with extended abstract in English).

Allar, A.D., Beler Baykal, B. 2013 Phosphorus recovery from source separated human urine upon processing with clinoptilolite. *Proceedings of the Water Environment Federation, Nutrient 2013*, 117-124.

Allar, A.D., Beler Baykal, B. 2016 An investigation of applicability of nutrients recovered from urine diversion in a summer housing site: Self-sufficiency based on nitrogen balance. *Water Science and Technology* **73**(3), 576-581.

Allar, A.D., Beler Baykal, B. 2015 Stagewise processing of yellow water using clinoptilolite for N&P recovery and higher residual quality. *Water Science and Technology* **71**(12), 1869-1874.

Allar Emek, A.D., Beler Baykal, B. 2016 Continuous versus batch contacting for nutrient removal from human urine upon processing with clinoptilolite-II: Surface concentrations and operation times. *3rd International Conference on Recycling and Reuse*, September 28-30, Istanbul, Turkey.

Basakcilardan-Kabakci, S., Ipekoglu, A.N., Talinli, I. 2007 Recovery of ammonia from human urine by stripping and absorption. *Environmental Engineering Science* **24**(5), 615-624.

Beler Baykal, B., Allar, A.D., Bayram, S. 2011 Nitrogen recovery from source-separated human urine using clinoptilolite and preliminary results of its use as fertilizer. *Water Science and Technology* **63**(4), 811-817.

Beler Baykal, B., Bayram, S. 2005 An appraisal of the use of human urine in agriculture. *Proceeding of IWA/IWWA 9th International Conference - ECOSAN India,* November 25-26, Mumbai, India, 138-144.

Beler Baykal, B., Bayram, S., Akkaymak, E., Cinar, S. 2004 Removal of ammonium from human urine through ion exchange with clinoptilolite and its recovery for further reuse. *Water Science and Technology* **50**(6), 149-156.

Beler Baykal, B., Dogan, G. 2016 Two stage processing options for enhancing total nutrient recovery from source separated human urine to be used as fertilizer. *WEF/IWA Nutrient Removal and Recovery 2016*, July 10-13, Denver, USA.

Beler Baykal, B., Kocaturk, N.P., Allar, A.D., Sari, B. 2009 The effect of initial loading on the removal of ammonium and potassium from source separated human urine via clinoptilolite. *Water Science and Technology* **60**(10), 2515-2520.

Dogan, G. 2015 A comparative investigation on producing fertilizers from human urine through indirect routes. *Master Thesis,* Istanbul Technical University, Istanbul, Turkey (in Turkish with extended abstract in English).

Droste, R.L. 1997 Theory and Practice of Water and Wastewater Treatment. John Wiley &Sons, Inc, USA.

Ganrot, Z., Dave, G., Nilsson, E. 2007 Recovery of N and P from human urine by freezing, struvite precipitation and adsorption to zeolite and active carbon. *Bioresource Technology* **98**, 3112-3121.

Ganrot, Z., Slivka, A., Dave, G. 2008 Nutrient recovery from human urine using pretreated zeolite and struvite precipitation in combination with freezing-thawing and plant availability tests on common wheat. *Clean* **36**(1), 45-52.

Hoglund, C. 2001 Evaluation of microbial health risks associated with the reuse of source separated human urine. *PhD Thesis*, Department of Biotechnology, Royal Institute of Technology, Stockholm, Sweden.

Inan, H. 2001 Principles of ammonia/ammonia peaks removal by ion exchange from wastewater and the usage of Bigadic clinoptilolite. *PhD Thesis*, Istanbul Technical University, Istanbul, Turkey (in Turkish with extended abstract in English).

Kabdasli, I., Tunay, O., Islek, C., Erdinc, E., Huskalar, S., Tatli, M.B. 2006 Nitrogen recovery by urea hydrolysis and struvite precipitation from anthropogenic urine. *Water Science and Technology* **53**(12), 305-312.

Kocaturk, N.P., Beler Baykal, B. 2012 Recovery of plant nutrients from dilute solutions of human urine and preliminary investigations on pot trials. *Clean-Soil, Air, Water* **40**(5), 538-544.

O'Neal, J.A., Boyer, T.H. 2013 Phosphate recovery using hybrid anion exchange: Applications to source-separated urine and combined wastewater streams. *Water Research* **47**, 5003-5017.

O'Neal, J.A., Boyer, T.H. 2015 Phosphorus recovery from urine and anaerobic digester filtrate: comparison of adsorption-precipitation with direct precipitation. *Environmental Science: Water Research and Technology* (4), 481-492.

Tilley, E., Atwater, J., Mavinic, D. 2008 Recovery of struvite from stored urine. *Environmental Technology* **29**, 797-806.

WHO 2006 WHO Guidelines, Excreta and grey water use in agriculture. The safe use of wastewater, excreta and greywater. Volume IV, Switzerland.

Wilsenach, J.A., Schuurbiers, C.A.H., Loosdrecht, M.C.M. 2007 Phosphate and potassium recovery from source separated urine through struvite precipitation. *Water Research* **41**, 458-466.