MONITORING OF POTASSIUM CONTENT IN WASTEWATER TREATMENT PLANTS

KÁLIUM TARTALOM VIZSGÁLATA A SZENNYVÍZTÍSZTÍTÓ TELEPEKEN

LÁSZLÓ TUTOR – ANDRÁS BÉRES – ANDRÁS BARCZI –
MÁRK KÁLMÁN HORVÁTH – GÁBOR GÉCZI
ifjtutor@gmail.com

Abstract

Partially treated wastewater can potentially provide a reliable and constant source of water and nutrients for hydroponic crop production. It is essential to determine the macronutrient content of the effluent, such as nitrogen (N), phosphorus (P), and potassium (K), to maximize the yield. Nitrogen (N) and phosphorus (P) measurements are essential daily tasks to be fulfilled, measurements were applied for multiple sources of K content only in this study, determining the exact daily content and concentration pattern. Influent and effluent K levels were measured separately.

According to measurements, it was observed that the concentration of K decreased significantly during treatment, with varying values as the wastewater passed through different treatment stages. Two locations with dissimilar technologies were sampled: Etyek, Hungary, semi-continuous batch system with suspended sludge, and South-Pest, Hungary, a continuous activated sludge system. The results were 39,7 mg/l in the influent and 7,5 mg/l in the effluent in Etyek, while South-Pest contained 28,9 mg/l in the influent and 24,5 mg/l K in the effluent respectively. Furthermore, the potassium content was measured in the Return Activated Sludge (RAS) line of South-Pest and found 50,8 mg/l concentration, however, it is being removed from wastewater with the Wasted Activated Sludge (WAS) in activated sludge systems.
Keywords: *Potassium (K) content, wastewater treatment, hydroculture*
JEL Code: *Q15, Q53, Q55*

Összefoglalás

A részlegesen kezelt szennyvíz megbízható és állandó víz- és tápanyagforrást biztosíthat a hidroponikus növénytermesztés számára. A maximális hozam elérése érdekében elengedhetetlen a makro tápanyagok, mint a nitrogén (N), a foszfor (P) és a kálium (K) mennyiségének ismerete a kezelt vízben. A nitrogén (N) és foszfor (P) mérése napi rendszerességgel végzett alapvető feladat, míg a K tartalom mérése a befolyó, elfolyó és különböző rendeltetésű szakaszokon jelen kutatás keretében történt.

A mérések alapján megfigyeltük, hogy a K koncentrációja a vízkezelés során szignifikánsan csökkent, különböző mértékben, ahogy a szennyvíz különböző kezelési szakaszokon haladt át. Két eltérő technológiával rendelkező helyszínen vettünk mintákat: Etyeken, egy fél-folytonos, lebegő iszapos rendszerből, valamint Dél-Pesten, egy folyamatos eleveniszapos rendszerből. Az eredmények szerint az összes K mennyisége Etyeken 39,7 mg/l volt a befolyó vízben és 7,5

mg/l a kifolyó vízben, míg Dél-Pesten a befolyó 28,9 mg/l-t, az kifolyó pedig 24,5 mg/l K-t tartalmazott. Ezenfelül a káliumtartalmat megmértük a Dél-pesti recirkulált aktivált iszap (RAS) vonalában is, ahol 50,8 mg/l koncentrációt találtunk. A kálium a rendszerből a fölösiszap-eltávolítás során (WAS) is távozik.
Kulcsszavak: *Kálium (K) tartalom, szennyvízkezelés, hidrokultúra*

Introduction

Discharging untreated wastewater into natural water bodies may cause eutrophication: Based on the COUNCIL DIRECTIVE (1991) Urban Wastewater Treatment Directive definition of eutrophication is ‘the enrichment of water by nutrients, especially nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of water concerned (ANDERSEN et al., 2006, NAGY-MEZEI et al., 2024). This phenomenon leads to rapid algae overgrowth, water quality issues, accelerated sedimentation, decreased diversity, and even further undesirable environmental events. Eutrophication is primarily regarded to be caused by phosphorus and nitrogen, potassium has been considered less significant in the context of natural water quality (ALFARO et al., 2004).

Unlike sodium, potassium was not reported to increase phosphorus uptake, as the effect of sodium could be detrimental to the environment, as it was reported to increase phosphorus uptake by algae, inevitably leading to overgrowth. The effects of potassium and sodium on wastewater treatment processes and their impact on natural flora are still not properly defined (GRASSO et al., 1992). As the presence of wastewater treatment is partly triggered by the necessity to prevent eutrophication, the principal objective is the removal of BOD, N, and P (METCALF et al., 1991). Nitrogen, phosphorous, and organic matter can be controlled/treated by typical treatment processes. The concentration of potassium has received less attention and is claimed to not be reduced during treatment processes. (ARIENZO et al., 2009, BESZÉDES et al., 2020, GWENZI et al., 2016, HORVÁTH et al., 2024, KIRCHMANN et al., 2017).

Furthermore, potassium in wastewater is occasionally undesirable as it may affect water treatment processes such as sedimentation and dewatering characteristics (HIGGINS – NOVAK, 1997). Potassium is required for a particular process in wastewater treatment. A wastewater treatment plant (WWTP) designed for biological phosphorus removal may have a short or long-term shortage of potassium in the influent. WWTPs designed to remove phosphorus have been exposed to varying ratios of potassium to phosphorus in the influent water. By simulating realistic conditions, it has been demonstrated that potassium is an essential factor in biological phosphorus removal processes (BRDJANOVIC et al., 1996, NDOUNG et al, 2023, PANTOJA, et al., 2023, QADIR et al., 2020).

Experimental measurement demonstrated that the addition of moderate amounts of potassium effectively alleviates the inhibiting effect of high salt levels on the process of Anaerobic Digestion. Potassium, like other ions, is potentially toxic above specific concentrations, which is an ecological concern when the range of toxicity is overlapping with concentrations released into natural water bodies (TALLING, 2010). The natural sources of potassium can be summarized as follows: the potassium content of precipitation is negligible, ranging from 0.1 to 4 mg/l in different geographic regions. The annual averages in 1991 and 1992 are in a range between 0.2 and 0.9 mg/l, thus remaining below 1 mg/l. The potassium released during rock weathering predominantly binds to the solid phase of the soil, so the K concentration in standing and running waters also remains low, rarely exceeding 10 mg/l. The potassium content of precipitation does not reach 1 mg/l at any sampled site, and the annual load in kg/ha is only 3 kg. The K concentration of water percolating through the soil is around 1-2 mg/l. It is generally considered that other parameters might be more relevant to monitor contamination, although K concentrations in drinking water and groundwater do not exceed 12 ppm, even in intensively cultivated agricultural areas (KÁDÁR, 1993). Urine is a significant source of K^+ in the effluent of municipal WWTPs, however other industrial and agricultural applications (such as olive oil mills, piggeries, and vineries) are also responsible for environmental potassium loading (NÖDLER et al., 2011).

The design of sanitation technologies for agricultural systems is an emerging topic. Combining the two systems (sanitation and agriculture) has the potential of creating an integrated, closed-loop system in which nutrients and water required for plant growth can be recycled from municipal wastewater and reused in crop production. However, the shortage of land for crop production is frequently limiting the agricultural reuse of wastewater. Hydroponic systems provide an opportunity for municipal wastewater treatment to recover water and nutrients from sanitation technologies and reuse them for horticulture (MAGWAZA et al., 2020, AL RAMAHI et al., 2020, CALABRIA, 2014, KARDOS et al., 2022).

While potassium is rarely considered as a substance subject to nutrient removal, it is common knowledge that it is considered as one of the plantal macronutrients. There are 14 inorganic elements required by plants to complete a full life cycle. These are the essential plant nutrients, grouped into macronutrients and micronutrients based on their concentration in plant dry matter. The macronutrients are: nitrogen (N), phosphorus (P), sulfur (S), potassium (K), calcium (Ca), and magnesium (Mg) (DE BANG et al., 2021). According to TALLING – LEMOALLE (1998) K is required by aquatic macrophytes in 2 to 4% of their dry matter, which is approximately the same magnitude as their Nitrogen content, therefore its importance is not negligible.

Wastewater is considered to be an efficient source of nutrients, although AKHTAR et al. (2012), for instance, reported that it could not meet the total nutrient requirements of wheat entirely. However, it reduced the N/P/K fertilizer doses, thus solving the irrigation water and nutrient source for the plants, bridging the gap between water demand and water availability. In three experiments, 80 $kg{\cdot}N{\cdot}ha^{-1}$, 40 $kg{\cdot}P{\cdot}ha^{-1}$ and 30 $kg{\cdot}K{\cdot}ha^{-1}$ in combination with 100% wastewater proved optimum doses, respectively. Similar results were gathered by CARVALHO et al. (2018), where they found that lettuce raised in a wastewater hydroponic system suffered well-identifiable potassium deprivation syndromes.

Available knowledge about the fate of potassium during wastewater treatment processes promotes the development of solutions and technologies necessary for its use in agricultural applications.

Material and Methods

Locations

The samples were collected from two locations, from two different systems in Hungary between February and June of 2024.

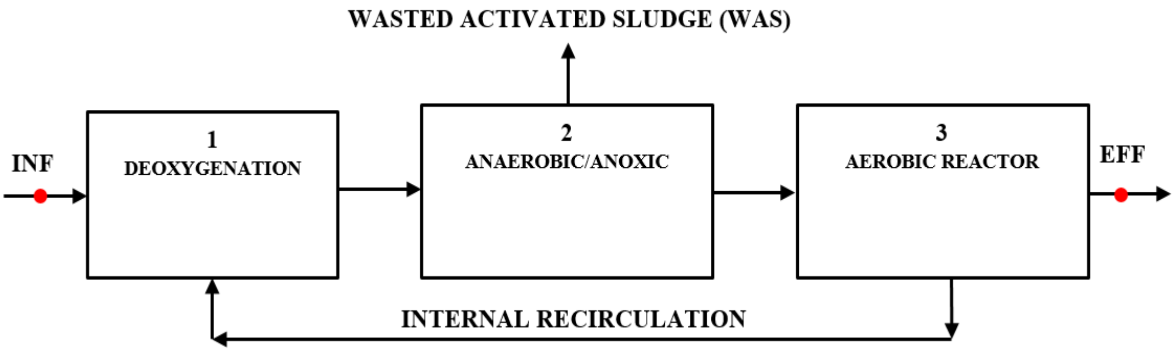

Figure 1. Process scheme of Organica Fed Batch Reactor, semi-continuous system with sampling points (red dots)

Figure 2. Planted Fed Batch Reactor surface in Etyek Wastewater Treatment Plant (EWTP), Hungary

First group of samples were collected in Etyek (Hungary) Wastewater Treatment Plant (EWTP) (Fig. 1 and 2), from an Organica Fed Batch Reactor (FBR) which is a semi-continuous batch system. The system consists of three vessels, a 29 m^3 deoxygenation chamber, a 157 m^3 anaerobic/anoxic tank and a 463 m^3 aeration tank. The deoxygenation chamber is connected to the aeration tank through a collection weir along the aerated reactor’s long edge, opening into the deoxygenation chamber with a pipe below the waterline. The water is leaving to the anaerobic/anoxic through a slit close to the basin bottom. The water flow is therefore vertical downwards. The water’s dissolved oxygen (DO) content is depleted during the short hydraulic retention time (HRT). The anaerobic/anoxic chamber is equipped with a mixer and a treated water collection system, which extends to the aerated tank. The anaerobic/anoxic tank has a wall opening towards the aerated tank with a propeller pump to sustain recirculation during the reaction phase. The aeration tank is equipped with tube diffusers, DO, and depth sensors.

The sequence of operation is 132 m^3 filling for a batch (into the ana/anox tank), approximately for 45 min, without recirculation. After 180 minutes of reaction phase (aeration and recirculation) a 45 min settling phase and a 30 minute effluent decanting is following. Internal circulation is continuous and the wasted activated sludge (WAS) is drained every ~5 hours. The treated effluent (EFF) is sent to the recipient body.

The second group of samples were collected at South Pest Wastewater Treatment Plant (SPWTP), from an Activated Sludge (AS) continuous system (Fig. 3 and 4.). The reactors are in an arrangement of eight, their volumes are 295 m^3 each, two reactors without aeration and six reactors including aeration, an average feed of 10 985 m^3/d, and also a Nitrate recirculation line of 5000 m^3/d. The average sludge concentration was around 2,4 g/l.

Both systems are Organica-designed systems, including installed vegetation, with additional root surface in the water.

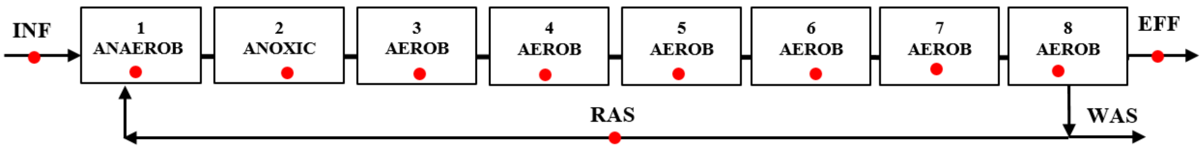

Figure 3. Process scheme of the sampled part of the continuous activated sludge wastewater treatment plant with sampling points (red dots)

Figure 4. South Pest Wastewater Treatment Plant (SPWTP), Hungary

Sampling

The influent samples (INF) were taken from the treated influent, the treatments were in case of Etyek 3 mm hole size screen, in case of South Pest 10 mm bar screen and primary clarifier. The effluent samples (EFF) were taken from the treated water tank in EWTP and from the secondary clarifiers in SPWTP. Both locations had partial vegetation coverage as Organica designs have in general. In 2024 five sets of samples from the SPWTP were taken from the sampling points shown on the Fig. 3. Three sets of samples from EWTP were taken paralelly (Fig. 1). All sludge samples are taken from SPWTP.

Samples were transported to and analyzed by Laboratory of MATE Gödöllő, Department of Environmental Analysis and Technologies; by standard of MSZ 1484-3:2006 and MSZ 1484-3:2006 for identifying Total K content. The wastewater samples were received in plastic containers and were stored cold.

The samples were homogenized and warmed to room temperature (20±2°C), then aliquots of 10 ml transferred directly into the liner of the microwave digester's (MARS5, CEM, North Carolina, USA) liner using an autopipette. 5 ml of 65 m/m% HNO_3 and 3 ml of 30 m/m% H_2O_2 reagents were added to the samples. Samples were filtered (MN640, Macherey-Nagel, France) after full digestion, topped up to 25 ml (dilution of 2,5 times) and were transferred to centrifuge pipes. The measurements of K and P were performed using a HORIBA JobinYvon ACTIVA-M ICP-OES device (Horiba Ltd, UK). The calibration curve points were prepared from VWR 85025.180 multi-element standard solution, and for the QC sample, we used CPA-Chem CRM (Certified Reference Materials).

Statistical methods

Descriptive statistics were applied for evaluation of the results, and the significant decrease in potassium content was confirmed using a two-sample t-test. The hypothesis is that the expected value of the potassium content in samples taken from the influent and the effluent is the same, meaning that the potassium content of the wastewater does not change significantly during the process.

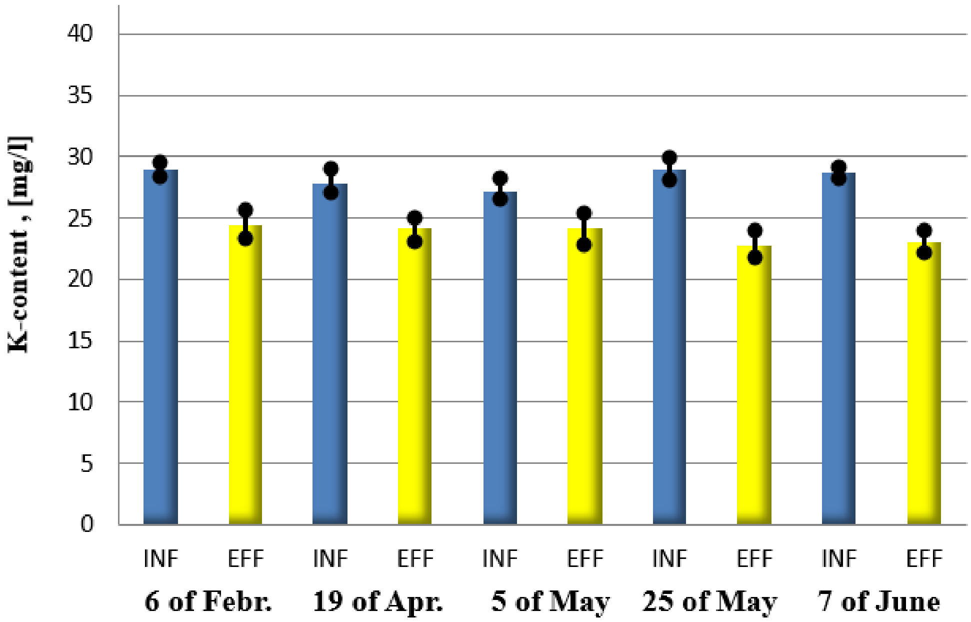

Figure 5. Average Potassium content with minimum and maximum values of influent (INF) and effluent (EFF) wastewater in the SPWTP in 2024

Results and Discussion

Based on the K values measured in the samples collected at SPWTP the K content of the wastewater is decreased during treatment, as it is presented by Figure 5.

Table 1. Statistical analysis to verify the significant decrease in potassium in the SPWTP

	06/02/2024		19/04/2024		10/05/2024		24/05/2024		07/06/2024	
Expected value	28.92	24.50	27.84	24.24	27.11	24.12	28.96	22.78	28.74	23.02
Variance	0.20	0.78	0.57	0.44	0.32	0.72	0.28	0.56	0.10	0.35
F_{sz} value	0.25		1.30		0.45		0.51		0.28	
F_p value	0.35		2.82		0.35		0.35		0.35	
t_{sz} value	15.48		12.39		10.14		23.44		29.51	
t_p value	2.07		2.07		2.09		2.09		2.07	
Results	$\|t_{sz}\| > t_p$		$\|t_{sz}\| > t_p$		$\|t_{sz}\| > t_p$		$\|t_{sz}\| > t_p$		$\|t_{sz}\| > t_p$	

F – The value of *F*-test for comparing the deviation of the two sample groups
t – The value of the *t*-test for comparing the average of the two sample groups
sz(index) – calculated value from the dataset
p(index) – lookup value for a significance level of $p < 0.05$

According to Table 1. since all the calculated *t*-value is above the *t*-value corresponding to a significance level of 0.05, the hypothesis is rejected and conclude that the technology shows a significant K-drop.

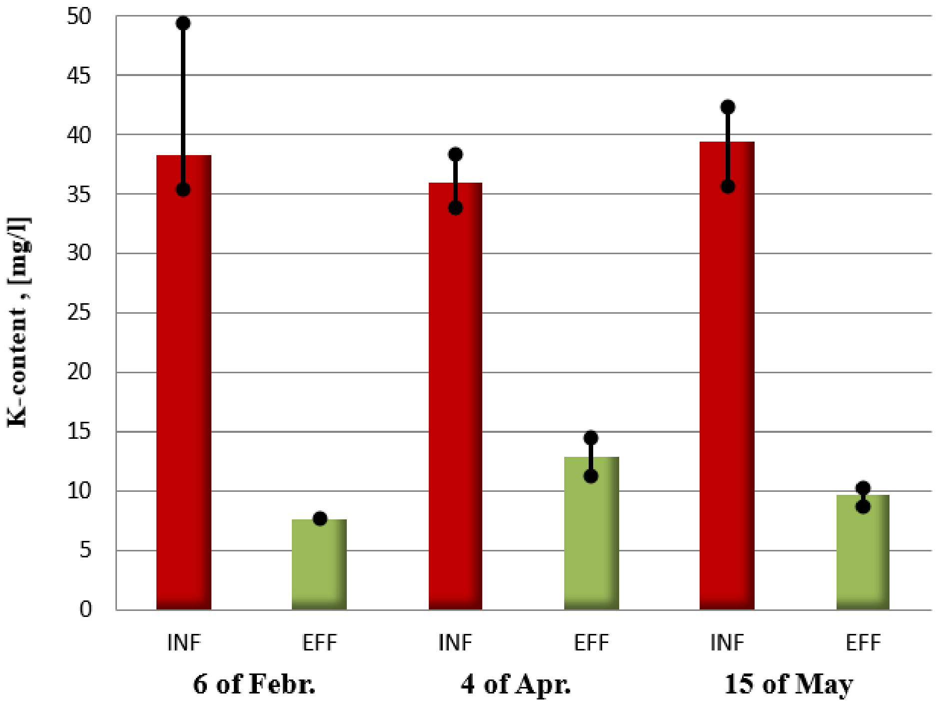

Figure 6. Average Potassium content with minimum and maximum values of the influent (INF) and effluent (EFF) measurement points in 2024 at the EWTP

The samples taken from EWTP show an even more pronounced decrease in K. The influent contains slightly more K than in SPWTP; but the effluent shows an even more significant decrease, as demonstrated on Figure 6.
Similar to SPWTP since all the calculated t-value is above the t-value (Table 2.) corresponding to a significance level of 0.05, the previous rejection of the hypothesis is confirmed here as well, and conclude that the technology shows a significant K content decreasing.

Table 2 Statistical analysis to verify the significant decrease in potassium in the EWTP

	06/02/2024		04/04/2024		15/05/2024	
Expected value	38.35	7.57	36.04	12.81	39.45	9.63
Variance	25.32	0.01	2.54	1.12	6.77	0.47
F_{sz} value	2046.48		2.27		14.28	
F_p value	4.28		4.28		4.28	
t_{sz} value	16.18		32.13		29.31	
t_p value	2.45		2.18		2.36	
Results	$\lvert t_{sz}\rvert > t_p$		$\lvert t_{sz}\rvert > t_p$		$\lvert t_{sz}\rvert > t_p$	

F – The value of *F*-test for comparing the deviation of the two sample groups
t – The value of the *t*-test for comparing the average of the two sample groups
sz(index) – calculated value from the dataset
p(index) – lookup value for a significance level of $p < 0.05$

At the SPWTP, the K content was measured at designated points in the technology as shown in Figure 3 to calculate the NPK ratio for the main hydroponic related test series. The results on Figure 7 presents that the initial K content is immediately increased as the Return Activated Sludge (RAS) got mixed to the wastewater stream. The total potassium concentrations were stagnant throughout the process, and post-settling they dropped below the initial influent values. It demonstrates that the total potassium content of the influent is removed through the treatment by the AS treatment. The K content of RAS based on the measurements of this study was 50.84±1.87 mg/l. (The N and P data is not shown.)

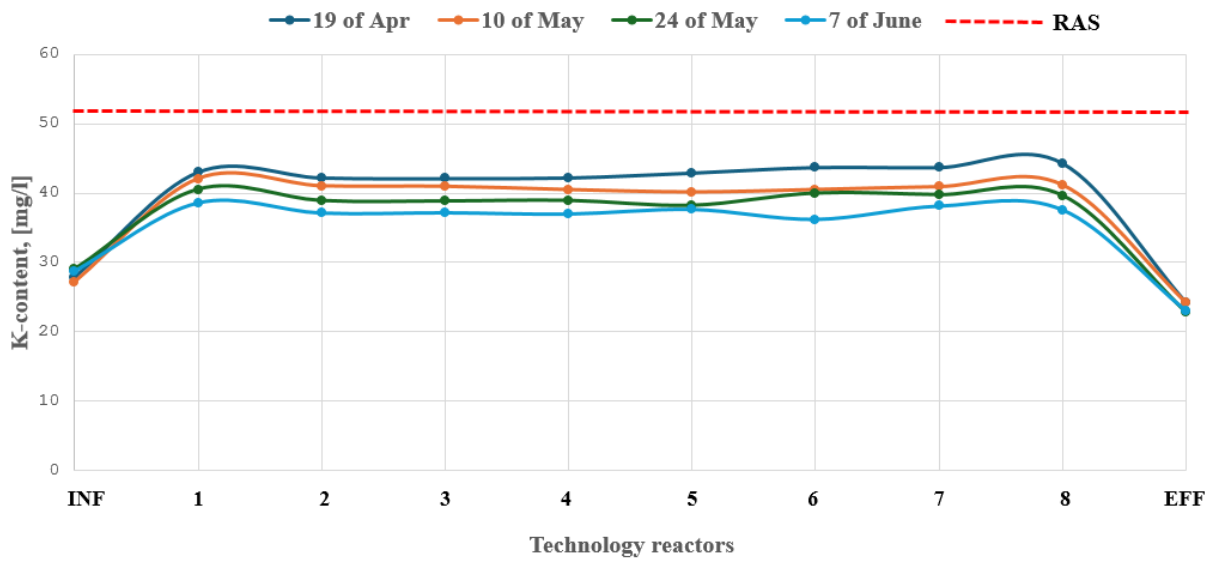

Figure 7 The change in K content along the technological process of SPWTP

This research demonstrates that K is consumed during the treatment process and is transferred to the RAS system and discharged from the system through the sludge loss process, causing partial K removal, and resulting in a considerable K decrease in the effluent. The decrease is dependent on the applied technology.

The results form a contrast to the statements of ARIENZO et al. (2009) as they state that the levels of potassium are not reduced during typical treatment processes, in fact, the concentration often increases due to evaporation from wastewater treatment and storage ponds. Our results of this research disprove this statement.

Conclusions

As it is found by BRDJANOVIC et al. (1996) and TALLING (2010) certain treatment processes require the presence of a certain level of K in the wastewater being processed. The presence of K in wastewater is not irrelevant, and its decrease marks its necessity. This study can contribute to further optimizing wastewater treatment processes. As two AS-based but dissimilar technologies were evaluated, it would be necessary to extend the research to other non-AS-based technologies, such as moving bed biofilm reactors, fixed bed biofilm reactors, trickling filters, membrane bioreactors, artificial wetlands, etc. The methods applied have been used for the determination of total potassium and are currently focused on the forms of potassium accessible to plants; adjustments to the methods may be necessary.

Acknowledgments

The research was supported by the project 'The feasibility of the circular economy during national defense activities' of 2021 Thematic Excellence Programme of the National Research, Development and Innovation Office under grant no.: TKP2021-NVA-22, led by the Centre for Circular Economy Analysis. Moreover, the doctoral student's work was supported by the Doctoral School of Environmental Sciences, MATE Hungarian University of Agriculture and Life Sciences.

References

AKHTAR, N.A.N. – INAM, A.A. – INAM, A.A. – KHAN, N.A. (2012): Effects of city wastewater on the characteristics of wheat with varying doses of nitrogen, phosphorus, and potassium. Recent Research in Science and Technology, 4(5), 18-29. https://updatepublishing.com/journal/index.php/rrst/article/view/895

AL RAMAHI, M – BESZÉDES, S. – KESZTHELYI-SZABÓ, G. (2020): The effect of hydrothermal treatment on industrial wastewater: Hungary as a case study, Progress in Agricultural Engineering Sciences, 16(S1), 45-51. https://doi.org/10.1556/446.2020.10005ALFARO

M.A. – JARVIS, S.C. – GREGORY, P.J. (2004): Factors affecting potassium leaching in different soils. Soil Use Manage. 20, 182–189. https://doi.org/10.1111/j.1475-2743.2004.tb00355.x

ANDERSEN, J.H. – SCHLÜTER, L. – ÆRTEBJERG, G. (2006): Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. Journal of plankton research, 28(7) 621-628. http://plankt.oxfordjournals.org/cgi/content/abstract/28/7/621

ARIENZO, M. – CHRISTEN, E.W. – QUAYLE, W. – KUMAR A. (2009): A review of the fate of potassium in the soil–plant system after land application of wastewaters. Journal of Hazardous Materials, 164(2-3), 415-422. https://doi.org/10.1016/j.jhazmat.2008.08.095

de BANG, T.C. – HUSTED, S. – LAURSEN, K.H. – PERSSON, D.P. – SCHJOERRING, J.K. (2021): The molecular–physiological functions of mineral macronutrients and their consequences for deficiency symptoms in plants. New Phytol, 229, 2446-2469. https://doi.org/10.1111/nph.17074

BESZÉDES, S. – JÁKÓI, Z. – LEMMER, B. – CZUPY, I. – HODÚR, C. (2020): Detection of the efficiency of enzymatic hydrolysis and fermentation processes by dielectric measurement Hungarian Agricultral Engineering 37, 21-26. http://doi.org/10.17676/HAE.2020.37.21

BRDJANOVIC D. – HOOIJMANS C.M. – VAN LOOSDRECHT M.C.M. – ALAERTS G.J. – HEIJNEN J.J. (1996): The dynamic effects of potassium limitation on biological phosphorus removal. Water Research, 30(10), 2323-2328. https://doi.org/10.1016/0043-1354(96)00121-2
CALABRIA, J.L. (2014): Wastewater nutrient recovery using anaerobic membrane bioreactor (AnMBR) permeate for hydroponic fertigation. Graduate Theses and Dissertations, University of South Florida, 94p. http://scholarcommons.usf.edu/etd/5348
CARVALHO, R.S.C. – BASTOS, R.G. – SOUZA, C.F. (2018): Influence of the use of wastewater on nutrient absorption and production of lettuce grown in a hydroponic system. Agricultural Water Management, 203, 311-321. https://doi.org/10.1016/j.agwat.2018.03.028
COUNCIL DIRECTIVE 91/271/EEC of 21 May 1991 concerning urban waste-water treatment http://data.europa.eu/eli/dir/1991/271/oj
GRASSO, D. – STREVETT, K. – PESARI, H. (1992): Impact of sodium and potassium on environmental systems. Journal of Environmental Systems, 22(4), 297-323. https://doi.org/10.2190/rrnd-6y9q-jn16-06nd
GWENZI, W. – MUZAVA, M. – MAPANDA, F. – TAURO T.P. (2016): Comparative short-term effects of sewage sludge and its biochar on soil properties, maize growth and uptake of nutrients on a tropical clay soil in Zimbabwe, Journal of Integrative Agriculture, 15(1), 1395-1406. https://doi.org/10.1016/S2095-3119(15)61154-6
HIGGINS, M.J. – NOVAK, J.T. (1997): The effect of cations on the settling and dewatering of activated sludges: laboratory results. Water Environment Research, 69(2), 215-224. https://doi.org/10.2175/106143097X125371
HORVÁTH, J. – KÁTAI, L. – SZABÓ, I. – KORZENSZKY, P. (2024): An Electrical Conductivity Sensor for the Selective Determination of Soil Salinity. Sensors, 24(11), 3296 https://doi.org/10.3390/s24113296
KÁDÁR, I. (1993): A kálium-ellátás helyzete Magyarországon. (The state of potassium supply in Hungary) KTM; MTA TAKI, 112p.
KARDOS, L. – ERŐSS, A. – NAGY-MEZEI, CS. – BEZSENYI, A. –CHEN, H. – BORGES SILVA, L.R. (2022): A kommunális szennyvíziszap vermikomposztálásának összefoglaló értékelése, Journal of Central European Green Innovation 10 (Suppl 1), 197–210. https://doi.org/10.33038/jcegi.3511
KIRCHMANN, H. – BÖRJESSON, G. – KÄTTERER, T. – COHEN, Y. (2017): From agricultural use of sewage sludge to nutrient extraction: A soil science outlook. Ambio 46, 143–154. https://doi.org/10.1007/s13280-016-0816-3
MAGWAZA, S.T. – MAGWAZA, L.S. – ODINDO, A.O. – MDITSHWA, A. (2020): Hydroponic technology as decentralised system for domestic wastewater treatment and vegetable production in urban agriculture: A review. Science of the Total Environment 698, 134154. https://doi.org/10.1016/j.scitotenv.2019.134154
METCALF, L. – EDDY, H.P. – TCHOBANOGLOUS, G. (1991): Wastewater engineering: treatment, disposal, and reuse. 4 New York: McGraw-Hill.
NAGY-MEZEI, CS. – BEZSENYI, A. – GYARMATI, I. – KARDOS, L. (2024): Comparison of the Quaternary Treatment Technologies in Municipal Wastewater Purification, Journal of Central European Green Innovation 12(1–2), 35–49. https://doi.org/10.33038/jcegi.6334
NDOUNG O.C.N. – SOUZA L.R. – FACHINI J. – LEÃO T.P. – SANDRI D. – FIGUEIREDO C.C. (2023): Dynamics of potassium released from sewage sludge biochar fertilizers in soil. Journal Environmental Management, 119057. https://doi.org/10.1016/j.jenvman.2023.119057
NÖDLER, K. – LICHA, T. – FISCHER, S. – WAGNER, B. – SAUTER M. (2011): A case study on the correlation of micro-contaminants and potassium in the Leine River (Germany). Applied Geochemistry, 26(12), 2172-2180. https://doi.org/10.1016/j.apgeochem.2011.08.001
PANTOJA, F. – SUKMANA, H. – BESZÉDES, S. – LÁSZLÓ, ZS. (2023): Removal of ammonium and phosphates from aqueous solutions by biochar produced from agricultural

waste Journal of Material Cycles and Waste Management, 25(4), 1921-1934. (2023) https://doi.org/10.1007/s10163-023-01687-8
QADIR, M. – DRECHSEL, P. – JIMÉNEZ-CISNEROS, B. – KIM, Y. – PRAMANIK, A., MEHTA, P. – OLANIYAN, O. (2020): Global and regional potential of wastewater as a water, nutrient and energy source. Natural Resources Forum, 44, 40–51. https://doi.org/10.1111/1477-8947.12187
TALLING, J.F. (2010): Potassium - a non-limiting nutrient in fresh waters? Freshwater Reviews, 3(2), 97-104. https://doi.org/10.1608/FRJ-3.2.1
TALLING, J.F. LEMOALLE, J. (1998): Ecological dynamics of tropical inland waters. Cambridge University Press, 441p.

Authors

László Tutor
PhD student
Doctoral School of Environmental Science, Hungarian University of Agriculture and Life Science, Szent István Campus, Gödöllő, Hungary
ifjtutor@gmail.com

András Béres PhD
Campus Director, Head of Laboratory Centre
University Laboratory Center, Hungarian University of Agriculture and Life Science, Szent István Campus, Gödöllő, Hungary
beres.andras@uni-mate.hu

András Barczi PhD
Assistant Professor
Department of Agricultural Economics and Policy, Institute of Agricultural and Food Economics, Hungarian University of Agriculture and Life Science, Szent István Campus, Gödöllő, Hungary
barczi.andras@uni-mate.hu

Márk Kálmán Horváth PhD
Associate Professor, Head of Department
Department of Environmental Analysis and Technologies, Institute of Environmental Science, Hungarian University of Agriculture and Life Science, Szent István Campus, Gödöllő, Hungary
horvath.mark.kalman@uni-mate.hu

Gábor Géczi PhD
Associate Professor, supervisor
Department of Environmental Analysis and Technologies, Institute of Environmental Science, Hungarian University of Agriculture and Life Science, Szent István Campus, Gödöllő, Hungary
geczi.gabor@uni-mate.hu