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Investigation of the Application of Coagulants in case of Domestic Greywater Fraction

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Abstract

During our research work, we examined the removal of contaminants from synthetically produced bathing waters using different coagulants and studied the efficiency and the mechanism of coagulation-flocculation processes in detail. In our work, we performed experiments with two different types of coagulants (iron(III) chloride and polyelectrolyte) and compared their efficiencies. The zeta potential and its change were monitored as a qualifying parameter while other water quality parameters were also analyzed. In our experiments, a newly acquired flocculator device was also used to study the coagulation-flocculation processes of larger volume samples. The main goal of our research is to promote the sustainable management of drinking water quality and to study the bathing water reuse possibilities.

Keywords: *synthetic greywater, iron(III) chloride, polyelectrolyte, reuse.*

1. Introduction

According to the first point of the European Water Charter, “There is no life without water!”, that is, water as a living medium is vital. Ensuring the right quantity and quality of drinking water is a global problem today. Unfortunately, part of the world’s population does not have access to the daily amount of drinking water they need. It highlights the importance of managing the water, protecting this life-saving treasure from, e.g. the challenges of climate change. The so-called greywater fraction generated by various activities in households, such as washing dishes, showers, washing, cleaning, can be an effective alternative source, especially for activities that do not require drinking water quality, such as flushing toilets or even irrigation.

2. About greywater

In recent decades, especially in developing countries, the utilization of greywater has become the focus of attention as one of the solutions to water scarcity, and the utilization of this faction is still developing dynamically in the world. Greywater (GW) is the used water fraction in households that comes from washing dishes, bathing, washing, showering, washing hands, and washing clothes. That is the wastewater that is generated in the household and does not include the water used to flush the toilet. The literature classifies greywater fractions into two major groups: high pollutant greywater (HGW) and low pollutant greywater (LGW) fractions. The latter group includes mainly GW from bathrooms and hand washing. These mainly include soap, shampoo, body care products, as well as fats, oils, or even traces of faeces and urine that dissolve from human skin and hair during the cleansing process [1–3].

In Hungary, the daily water consumption per capita is around 97.8-100 L [4]. The GW can be approx. 65-70 % of the wastewater flow. Furthermore, the less loaded fraction (LGW) can represent 50 % of the total amount of GW. Based on all this, there is great potential for the reuse of these fractions. Based on the daily bathroom routine most of the GW is generated from showering, bathing, and handwashing, as one is cleaned in some form almost every day. Of course, its characteristics and amount also depend on several factors [3].

Our research focuses on the potential utilization of this GW fraction, during which we tried to reduce the amount of the main pollutants in this used water fraction by applying chemical water treatment. Iron(III) chloride and polyelectrolyte-type treatment agents were tested as coagulants. We studied the efficacy of the two agents and flocculation equipment was used to efficiently follow the flocculation processes.

3. Material and methodology

The tests of the greywater samples were performed in the Water Quality Protection Laboratory of the Department of Environmental Engineering, Faculty of Engineering, University of Debrecen. Based on the research results of the Water/Wastewater Utilization research group of the department, we prepared synthetic bathing water with a constant composition as model water. Our goal was to create and model the bath-water fraction by adding detergent components to the drinking water and to study the effects of different coagulants. Freshly prepared synthetic bathwater of the same composition was used for each series of tests.

To characterize the composition of the samples, the so-called non-specific physical and chemical parameters were determined. Measurements focused on determining pH, zeta potential, specific electrical conductivity, turbidity, biological oxygen demand (BOD5), total organic carbon (T/DOC), and anionactive detergent content. WTW SenTix 41-3 pH electrode for pH measurement, Zetasizer Nano Z device for zeta potential and specific electrical conductivity, OxiTop IS 12 for BOD_5 measuring, and Shimadzu TOC-VCPN device to measure total organic carbon were used. The ISO 2271: 1989 standard was applied to determine the anionactive detergent content of the samples [5–7].

The bathwater was prepared by adding 4 components (shower gel, shampoo, corn germ oil, and plant nutrient concentrate) dissolved in drinking water at 40 °C. As a first step in the chemical treatment, iron(III) chloride was used as a treatment agent during the coagulation, which was added to the water samples in different volumes in the form of a 25 gL^{-1} stock solution. 100 ml aliquots were pipetted into the beaker from the GW samples. The purpose of the treatment was to remove the non-settleable colloidal particles, and to convert dissolved pollutants into insoluble ones. We continuously measured the so-called zeta potential values and based on the measured values, the optimal amount of chemical was determined to achieve a zeta potential between 0±5 mV. During the measurement processes, a rapid stirring of 5 minutes was used for each sample portion, which facilitated the efficient mixing of the coagulants at 300 rpm. Thereafter, slow stirring for 15 min at 25-50 rpm was used to support the flocculation processes. Using a subsequent settling time of 10–15 min, efficient separation was achieved, and the zeta potential of the sample from the upper, clearer liquid layer was followed.

In our research, we also performed an examination with another treatment agent, this is a so-called polyelectrolyte treatment agent (ACEFLOC 80902). Similar to the previous treatment agent described above, the water samples were added in different volume units as a 1 g/l stock solution. To determine the optimal chemical dose, 100 mL aliquots of the synthetically prepared GW sample were also treated.

4. Conclusions

4.1. Greywater quality parameters

Based on the method given in the Materials and Methods section, the GW sample was prepared from 4 constituents (shower gel, shampoo, corn germ oil, and plant nutrient source). The results obtained during our work were compared with the results of previous literature and the research group of the Department of Environmental Engineering of the Faculty of Engineering of the University of Debrecen. The group determined the qualitative and quantitative parameters of the GW generated in households in the Northern Great Plain region. Thirty different households were selected for the survey, which included dwellings, townhouses, and single-family homes. Using this research and many other foreign works of literature, we were able to delimit the quality characteristics of bathing water samples [8].

Table 1 contains the quality parameters characteristic of bathing waters as GW fraction available in the international literature, the data determined by the research group, and the test results of the raw GW samples measured by us.

The composition of the synthetic bathing water prepared for our studies was clearly very similar to that of real bathing water sample quality. The pH of the bathing water used for our measurements is the same as the actual bathing water data measured in the region. Specific electrical conductivity and zeta potential values may vary,

Table 1. *Comparison of bathing water quality*

Parameters	International data [3]	National data [8]	Own results
pH	7.3–7.5	6.73–7.95	7.82±0.29
Specific electrical conductivity (mS/cm)	0.014–0.89	0.412–0.610	1.21±0.563
Zéta-potential (mV)	–	0.00–(–33.00)	–17.01±0.32
Turbidity NTU	84.8–375.0	2.3–84.0	21.49±15.28
BOI_5 (mg/L)	40.2–424	6.67–253.3	100.67±8.14
DOC (mg/L)	–	7.71–87.76	65.80±25.09
ANA-detergents (mg/L)	14.9–61*	0.01–4.18*	14.25±6.12

**MBAS parameter, parameter, which is very similar to ANA values but measured with a different measurement solution*

Table 2. *Treatment with ferric chloride in 100 mL bathwater sample aliquots*

	$FeCl_3$ volume (ml)	pH	Specific electrical conductivity (mS/cm)	Zeta-potential (mV)	Standard Deviation/ Zeta-potentiall	Turbidity (NTU)
1.	0.90	6.39	0.98	–8.38	0.295	9.07
	1.00	6.09	1.01	–0.70	0.156	7.67
	1.05	5.64	1.05	11.70	0.058	9.61
	1.15	5.81	1.05	12.10	0.407	19.45
2.	0.50	6.47	0.96	–10.2	0.416	4.75
	0.70	6.06	0.99	–4.56	0.133	3.09
	0.85	5.77	1.04	5.54	0.111	4.94
	0.90	5.55	1.03	2.91	0.745	5.33
	0.95	5.59	1.02	2.55	0.182	4.63
	1.00	5.43	1.06	8.76	0.322	5.25
	1.30	3.33	1.31	39.10	0.140	64.76
3.	0.50	6.48	0.95	–10.0	0.494	5.11
	0.70	6.09	0.99	–5.82	0.444	16.24
	0.80	6.02	0.98	–2.60	0.193	5.82
	0.90	5.44	1.04	12.10	0.404	7.51
	1.10	5.11	1.02	19.90	0.808	18.54

possibly due to the presence of different ions found in other brands of shampoo or shower gel. Variable contaminants, dead epithelial cells, and hair may affect the BOD_5, TOC, and turbidity values. We found that we were able to formulate synthetic bathing water with very similar quality to that determined in both the national and international literature.

4.2. Evaluation of treatments with ferric chloride

Table 2 shows the results of a series of 3 parallel treatments with ferric chloride, and **Figure 1** shows the change in zeta potential as a function of the amount of chemical added to show the success of the coagulation.

We have found that iron(III) chloride is an effective treatment agent, with the optimal amount of treatment agents ranging from 170 to 213 mg/L. Thus, the measured zeta potential value of 0 ± 5 mV was achieved. During the treatment process, flock formation was intense, and the use of a slow mixing step aided in efficient flocculation processes and better sedimentation properties of impurities.

The zeta-potential measurement confirmed that the initial very negative value moved in the positive direction in the coagulation-flocculation process, and in the ideal range of -5 mV to +5 mV the tested system will be proven to be destabilizing, i.e. contaminants can be settled from the water sample. The pH of the tested solutions varied with the amount of chemical added, as the chemical dose increased, the pH of the solution decreased, which meant that the samples produced acidic acidity. The turbidity values also showed a decreasing trend as we approached the optimal range, since if there is a sufficient amount of coagulant in a given greywater sample, using the appropriate settling time, visually purified, treated water is obtained. Conductivity data increased proportionally with the treatment agent overdose, similar to the turbidity value.

4.3. Evaluation of treatments with a polyelectrolyte type treatment agent

Table 3. summarizes the measurement results obtained from the 3 series of parallel treatments performed.

We found that the optimal dose for the polyelectrolyte (PE) type treatment agent was between 33-43 mg/L, that is, significantly less chemical is required to effectively treat 1 litre of synthetic bathwater.

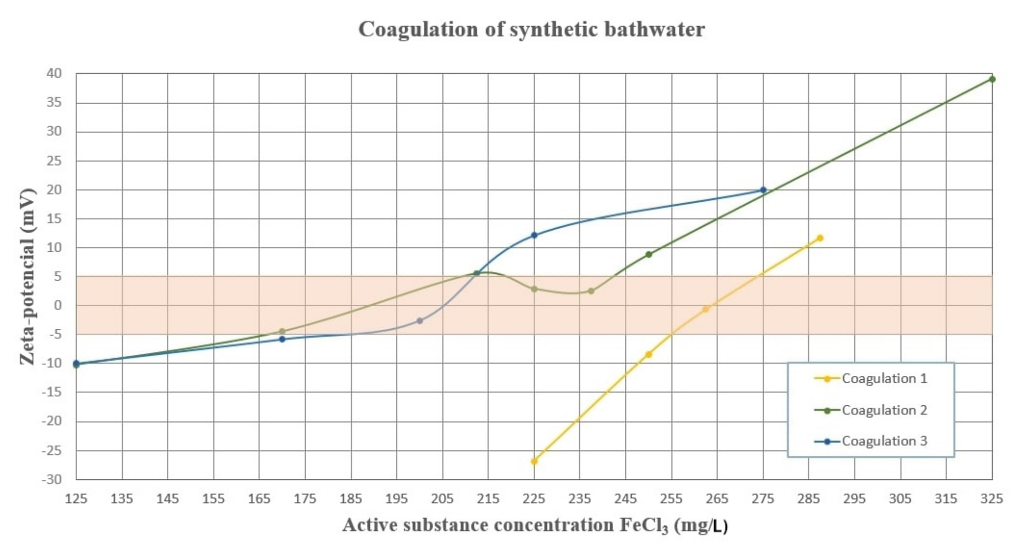

Figure 1. *Determination of the optimal amount of chemical in the case of ferric chloride.*

Table 3. *Coagulation with polyelectrolyte in 100 mL sample aliquots*

	PE volume (ml)	pH	Specific electrical conductivity (mS/cm)	Zéta-potential (mV)	Standard Deviation/ Zeta-potentia	Turbidity (NTU)
1.	0.50	8.35	0.85	–29.90	0.985	31.95
	1.00	8.43	0.84	–26.10	0.252	23.59
	1.25	8.40	0.86	–25.50	0.919	21.83
	1.50	8.39	0.86	–24.30	0.436	13.91
	5.00	8.36	0.78	26.10	0.819	31.50
2	2.00	8.34	0.85	–20.50	0.651	31.72
	3.00	8.31	0.83	–2.52	0.267	61.99
	3.30	8.25	0.80	3.60	1.500	71.30
	4.00	8.30	0.78	16.50	0.656	66.13
	5.00	8.31	0.81	29.10	0.379	79.73
3.	2.85	8.19	0.84	–19.40	0.351	8.87
	3.00	8.01	0.84	–12.20	0.100	10.22
	4.00	8.28	0.85	–6.15	0.648	4.26
	4.30	8.35	0.86	3.98	0.260	3.33
	5.00	8.28	0.88	19.30	0.889	94.97

With the addition of a polyelectrolyte solution in this series of experiments, the formation of flocs was intense and spectacular, and, as in the previous treatment, the use of slow stirring helped to achieve more efficient flocculation and then better settling. **Figure 2** illustrates the evolution of the optimal amount of chemicals as a function of zeta potential values.

An additional advantage of adding the treatment agent is that it does not shift the pH into the acidic range. Turbidity values decreased as they approached the optimal range. The specific electrical conductivity data did not increase significantly in proportion to the overdose of the treatment agent, similar to the turbidity value. That is, this treatment may be a good basis for treating larger volumes of greywater samples later. Based on all this, it is advisable to further study the conditions of treatment.

4.4. Scaling up, post-treatment, development of quality parameters

In a smaller volume, we determined the optimal amounts of chemicals only on 100 mL portions of the water to be treated with the help of a magnetic stirrer, while on a larger scale, a flocculator was used to assist. During scaling, we initially worked with 500 mL sample aliquots. The test sample aliquots were mixed at 300 rpm with the required multiple doses for both chemicals.

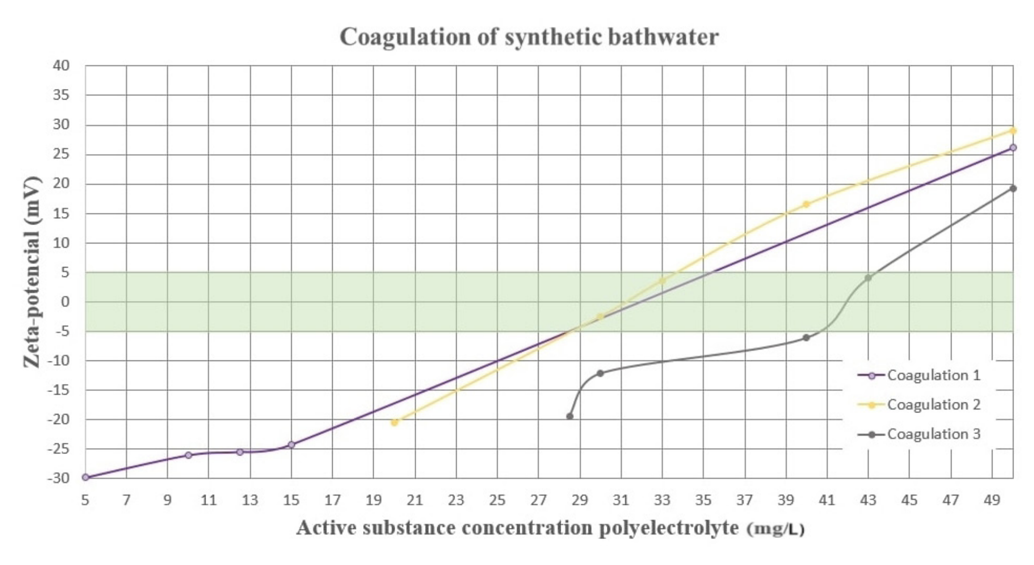

Figure 2. *Determination of the optimal amount of chemical in the case of polyelectrolyte stock solution.*

We found that the treatments performed well even in larger volumes, the previously determined optimum was sufficient for efficient contaminant removal, i.e. the examined greywater fraction can be treated well based on the scale increase. In our experiments, we also tested the coagulation-flocculation conditions and found that slow mixing for some time after chemical addition improves the formation of larger flocculants, so it is advisable to use it to produce better quality treated water.

Based on the experience with the 500 mL samples, we also performed our experiments on 1, 2, 3, and 4-litre samples. For larger volume samples, the sample was passed through a simple quartz sand filter after chemical treatment to remove settled contaminants. Based on all these, the **Tables 4–5.** summarizes the differences in the quality parameters of the untreated and coagulation-filtered water samples, thus characterizing the treatment efficiencies.

The tables well illustrate to us that although the two coagulants produced different data in two parameters, using the filtration as a post-treatment mechanism, almost the same quality of water is obtained as the result. The BOD5 and DOC values are the most prominent in the table, as it is clear how the chemical purification process takes place, i.e. how the content of contaminants in the water sample decreases.

Table 4. *Ferric chloride treatment agent and post-filtration water quality parameters*

$FeCl_3$	Raw sample	Treated sample	Filtered sample
pH	8.04	5.26	7.22
Specific electrical conductivity (mS/cm)	0.853	1.07	0.672
Zeta potential (mV)	–25.56	–4.76	–12.35
Turbidity NTU	10.02	3.93	0.20
BOI_5 (mg/L)	150	35	6
DOC (mg/L)	47.67	27.82	4.43

Table 5. *Polyelectrolyte treatment agent and post-filtration water quality parameters*

PE	Raw sample	Treated sample	Filtered sample
pH	7.92	8.15	7.83
Specific electrical conductivity (mS/cm)	0.946	0.925	0.754
Zeta potential (mV)	-30.50	4.38	-4.57
Turbidity NTU	54.05	6.33	0.17
BOI_5 (mg/l)	195	30	1.5
DOC (mg/l)	48.31	25.85	3.44

5. Summary

We have found that both treatment agents can be used effectively to treat greywater. Iron(III) chloride is an inexpensive and effective agent, but its use lowers the pH of the treated water, which may require subsequent neutralization. The polyelectrolyte type treatment agent is also effective even at lower doses, it does not lower the pH of the sample, but it is a more expensive material. Based on all this, it is advisable to further explore the treatment options and their possible new combinations to support sustainable water management.

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