Chemical treatments for bathroom greywater reuse

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Abstract: - One of today's major concerns, beside the constant increase in the demand for fresh water, is the inappropriate quality of water sources. The proper management of drinking water is essential and the alternatives for its substitution are to be taken into consideration where it is possible. Our investigations were aimed at the qualitative characterization of domestic greywaters and at their chemical treatment with recycling purposes. During the investigations simple trivalent metal salts were used as coagulants and the coagulation was tracked with the help of zeta potential measurement. The optimum quantity of the coagulant was determined in order to avoid wasting chemicals and loading the purified water. Both chemicals were needed in approx. the same quantity for producing the required zeta potential. The results of the treatments revealed an obvious quality improvement of the water samples. Aluminum sulphate proved to be more effective with the dissolved organic carbon content of the bathwater, while the microbial growth was decreased more effectively by ferric chloride.

Key-Words: - greywater, water treatment, coagulation, reuse, Zeta potential, microbial contamination

1 Introduction

Domestic greywaters include sewage waters generated in bathrooms and kitchens or during washing, however exclude those produced by flush toilets [1,2]. The issue of greywater recycling raised attention in the past decades, primarily as a possible solution for water shortages in developing countries, and it is performing a rapid growth on global level today [3, 4]. These countries have sought to reuse the collected sewage water for agricultural irrigation after a treatment. This water can effectively supply household activities (toilet flushing, soaking, window cleaning, vehicle washing, irrigation etc.) that do not require water of consumable quality [5]. By recycling greywaters the potable water consumption of households and the quantity of the produced and discharged wastewater can be considerably reduced [6,7]. A crucial point in greywater recycling is being aware of the water quality standards, on the basis of which, treatment methods facilitating safe reuse can be developed. Water classification provides a number of useful and reliable measuring devices, which help the accurate mapping of the contaminants [8]. The majority of the relevant researches analyze the organic, nutrient and microbiological contamination in greywaters.

A large range of technologies has been used for greywater recycling from simple 2-stage processes (coarse filtration and disinfection) to physical, physicochemical and biological processes.[9]

Greywater recycling result in significant floc production, and the flocs are to be removed. A part of the flocs can be removed by filtering, settling. Colloidal impurities, however, are more difficult to remove, since due to their small size, they cannot be simply filtered or settled. Colloid particles are negatively charged, stabilized in aqueous phase [10]. Coagulants and/or flocculants are needed to remove these particles, by terminating their stability. The aggregates, created in this way, can be mechanically removed from the contaminated waters [11, 12]. In most cases Al^{3+} and Fe^{3+} compounds are used for neutralizing charge. [12,14] The advantage of trivalent metal salts is their hydrolyzing effect. Dosing them into water, polyhydroxy compounds are produced, which neutralize the negative charge of colloid particles. As a result of the complex chemical processes, the metal ion with double or triple positive charge turn into neutral metal hydroxide $[Al(H_2O)_3(OH)_3]$. So called metal hydroxide complexes with positive charge are produced as hydrolysis side products.

During our research greywater samples taken from the Eastern region of Hungary were analyzed and treated by dosing different flocculants (iron(III)

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chloride ($FeCl_3$) and aluminum sulphate ($Al_2(SO_4)_3$). The effect of the dosed flocculants was examined by turbidity, dissolved organic carbon content and zeta potential measurements, and with microbiological rapid tests at the same time. Changes in zeta potential provide information on the stability and destability of the colloid system, while microbiological rapid tests can inform us about the decrease in the microbiological load in the water sample.

2 Materials and methods

2.1 Sample type and collection

Our research was performed in respect of households located in the capital of the Eastern region of the Great Hungarian Plain, in Debrecen. 10 different households were chosen for the research, including flats, terraced houses, and detached houses.
Greywater samples were collected from baths and showers for research purposes. The samples were contained in 1 liter glass containers, and after a refrigerated transport to the laboratory, they were stored at +4 °C until examination.
Besides performing research on the individual samples, the analysis and the treatment were performed on mixed samples as well. Mixed samples were prepared by mixing equal volumes of greywater samples from each individual sample.
The samples were filtered through 0.45 μm membrane filter and examined within 24 hours after sampling.

2.2 Coagulation experiments

For coagulation researches we took a mixed bathwater as starting material, which included greywater samples from 10 households.
During the researches ferric (III) chloride and aluminum sulphate were used as hydrolyzing metal salts, dosed into the given greywater samples in the form of solutions with different concentrations.
The zeta potential was constantly being measured, its changes were analyzed, and on the basis of the results obtained, the quantity of the chemical required to produce the optimum zeta potential was determined.
The flocculants were applied in aqueous solution format in order to perform faster stirring. The stock solution concentration of flocculants used in the researches was 20 g/dm^3, from which 2, 4, 6, 8 and 10-fold dilutions were made.
During the experiments 5, 10 and 15 cm^3 portions of flocculants with different concentrations were dosed into greywater samples of 100 cm^3 volume, with intensive stirring for 30 seconds (ARE Heating Magnetic Stirrer, level 4).
For measuring zeta potential, 45 ml of treated water sample was taken, and after 5 minutes of settling, the liquid column was sampled at 2/3 height for each measurement respectively.
In parallel with zeta potential measurements, turbidity of the water sample was being measured as well.

2.3 Analytical methods

Grey water samples were analysed for pH, electrical conductivity (EC), turbidity, dissolved organic carbon (DOC), zeta potential (ζ) and microbial load. For the measurement of pH and conductivity, Multiline P4 meter portable instrument was used (WTW GmbH, Weilheim, Germany), while daily calibration was performed using standard solutions. Turbidity (NTU) was measured with a turbidimeter Turb 555 IR (WTW GmbH, Weilheim, Germany). Zeta potential (mV) was determined using a Zetasizer Nano Z instrument (Malvern Instruments Ltd, Malvern, UK). DOC was measured using a total organic carbon analyzer Shimadzu TOC-Vcpn (Shimadzu Europe GmbH, Duisburg, Germany). Hygiene Monitor test kits (Transia GmbH, Ober-Mörlem, Germany) were used for characterization of the microbiological load of GW samples. These test kits are suitable for hygiene control according to DIN 10113-3 and EU Hygiene regulation (No. 852/2004) (REU, 2004). Two types of contact slides (TTC total count/total coliforms and CHROMagar E. coli/coliforms) were used simultaneously via the dipping method.

3 Results and discussion

3.1 Characteristics of greywater

The researches were started by simple physical and chemical examinations of the individual bathwater samples and the mixed sample. Table 1 summarizes the results of the examined parameters of the water samples. The pH value of the bathwaters appeared to be around neutral (6.8-8.0), the individual samples did not show significantly different extremes. The electrical conductivity of the greywater samples was between 519 µm and 610 µm, which values are considered low in terms of wastewater classification. The relatively low values indicate that this kind of greywater is much less loaded with dissolved salts. The turbidity values of the bathwater samples appear to vary considerably, with results ranging between 6 and 81 NTU, which indicate the variety in the floating content of the individual samples. For measuring DOC and ζ, we used greywater samples filtered through membrane filters (0.45 mm pore size). The average DOC concentration appeared to be 49±21 mg L^{-1}. One of our main objectives is to reduce organic content in greywater, which provides nutrition for microbes thus enabling their growth. ζ values appeared to be between -32.3 mV and -3.5 mV. The negative zeta potential values indicate a presence of colloidal particles in the water sample. It is also observable that the examined parameters of the mixed greywater in the last column of the table do not show considerable deviation from the average values resulting from the examination of the same parameters in the individual greywater samples.

Table 1 Physical and chemical features of the individual samples and the mixed bathwater sample

	Grey water			Mixed grey-water
	Extremes	Average	Deviation	
pH	6.8-8.0	7.6	0.3	7.7
EC (µS cm^{-1})	519-610	561	28	560
Turbidity (NTU)	6-81	31	25	25
DOC (mg L^{-1})	17-81	49	21	56
ζ (mV)	(-32.3)-(-3.5)	-17.9	9.53	-15.2

3.2 Optimal coagulant dosage

Figure 1 shows the zeta potential changes in relation to the quantity of the flocculent. The green stripe of the figure indicates the ζ domain (zeta potential is between +/-5 mV) that allows the colloidal impurities in the sample to coagulate. Under such circumstances the colloid system is destabilized, i.e. it is able to flocculate in the presence of metal hydroxides in the system. Having flocculated the greywater is reusable in certain areas of application (e.g. toilet flushing, irrigation). The figure shows that the optimal zeta potential value of the mixed greywater sample is achieved by dosing 10 cm^3 $FeCl_3$ solution of 2 g/dm^3 concentration (20 mg $FeCl_3$). Furthermore it is also revealed that in the case of aluminum sulphate, more than one experiments resulted in effective coagulation. $Al_2(SO_4)_3$ was possible to dose into 100 cm^3 bathwater sample in quantities ranging from 10 to 20 mg.

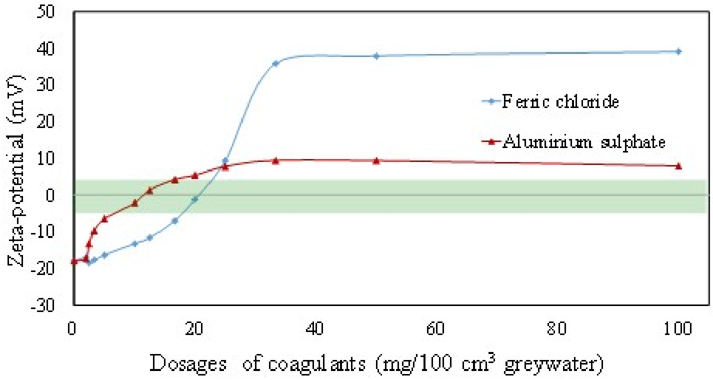

Fig. 1 Zeta potential changes as a result of coagulants dosed into the mixed bathwater

3.3 Effects of coagulants on DOC and microbial contamination

During the treatment of the greywater samples we used $FeCl_3$ and $Al_2(SO_4)_3$ coagulants, the optimal quantity of which was determined in the way discussed above. For examining the DOC content and the microbial load of the treated samples, the experiment was repeated by dosing the optimum quantity of flocculent into 200 cm^3 bathwater. Following the coagulation, turbidity and zeta potential measurements were performed in the way described under 2.2, and for further examinations the samples were filtered through Filtrak 389 filter paper (medium pore size). Table 2 summarizes the parameters of the mixed bathwater sample examined before and after the chemical treatments.

Table 2 Greywater characterization before and after treatment with different coagulants at optimum conditions

	Mixed sample	Treatment	
		with $FeCl_3$	with $Al_2(SO_4)_3$
pH	7.4	6.3	6.4
EC (µS/cm)	570	627	563
Turbidity (NTU)	28.3	0.2	0.7
DOC (mg/l)	41	25	21
ζ (mV)	-15.2	-8.37	-8.57

Table 2 makes it evident that a significant quality improvement can be achieved by using either of the coagulants. The turbidity of the bathwater samples proved to be 28.3 NTU before treatment, which value was decreased by over 97% to reach 0.2 and 0.7 NTU after treatment. The dissolved organic carbon content of the mixed sample was decreased by 39% as a result of the treatment with ferric chloride, and by 47% as a result of the aluminum sulphate treatment. Figure 2 shows the effect of coagulation on microorganism growth.

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The total plate count of 10^7 lgCFU mL^{-1} in both samples was reduced by at least two orders of magnitudes as a result of the treatment.
The total plate count and the coliform count of the sample proved to be smaller by at least an order of magnitude after $FeCl_3$ treatment than after $Al_2(SO_4)_3$ treatment.

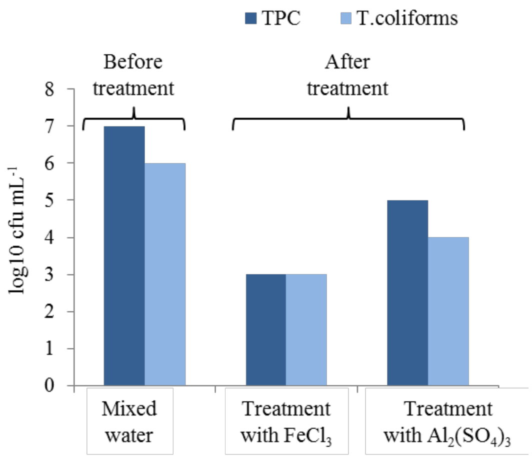

Fig. 2 Changes in the microbial load in the mixed bathwater as a result of the treatment

During comparison, both coagulants were found to be suitable for the pretreatment of greywater samples. In terms of the dissolved organic carbon content of the greywater, aluminum sulphate proved to be more effective, while the number of microbes were more effectively decreased by ferric chloride.

4 Conclusion

Our project performed the examination and chemical treatment of greywaters taken from 10 households. The physical and chemical features (EC, turbidity, DOC, ζ) of the greywaters were examined and their microbial load was analyzed. The examined parameters are of key importance in terms of recycling, their comprehensive knowledge is indispensable. Based on the results obtained through the examination of the qualitative and quantitative features of the greywaters, it is evident that from among treatment methods, mechanical treatments alone are not able to achieve the required purity, in this way these methods are recommended to be supplemented by chemical treatments. During the experiments aimed at the chemical treatment of greywaters, we determined - with the help of ζ measures - the optimum quantity of chemicals required for colloids to coagulate. It was also determined that ferric chloride and aluminum sulphate coagulants are needed in nearly equal amounts for the treatment of the mixed bathwater. During our experiments on treatment methods, the application of coagulants resulted in significant improvement in the quality of the treated water. We observed that the turbidity of the water sample was reduced by over 97%, the DOC content performed considerable improvement (i.e. decrease), and the microbial growth was reduced to a lesser extent as a result of the chemical treatment.

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