Treatment of grey water for urban water reuse

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Abstract

Adequately treated grey water is a suitable resource for urban water supply, where no drinking water quality is required. Grey water is collected from indoor sources other than toilets and kitchen sinks, such as showers and bathtubs, hand basins and washing machines.
Grey water has typically lower BOD_5, COD, N and P levels, is higher in temperature compared to domestic waste water, but higher concentrations of active surfactants are observed. In general similar treatment processes as for the treatment of municipal waste water can be used for treating grey water. Thus grey water treatment seems to be less complex as no nitrogen and phosphorus removal is necessary, and biochemical degradation rates are fast as a result of higher temperature especially at nearby treatment. Treated grey water can be used as service water, e.g. for toilet flushing and plant irrigation in intra-urban areas, which again fosters decentralized nearby treatment.
The pilot plant, which is part of a BMBF funded project (Semi-centralized Supply and Disposal Systems for Urban Areas in China, Part II: 02WD0607), consists of five different treatment units. The size of this whole pilot plant is about 1,500 population equivalents. For the pilot plant synthetic grey water will be composed by adding wash powder, tooth paste, bubble bath, shower gel etc. to drinking water. The formula is based on consumption data given by IKW (Industrieverband Körperpflege und Waschmittel e.V. = German Cosmetic, Toiletry, Perfumery and Detergent Association). In addition some municipal waste water is added to simulate microbial pollution as well as particular matter and grease. The composition of this synthetic grey water is in good compliance with published data of real grey water, which anyhow shows a wide variance.

Keywords
Characters of grey water, flocculation, reduction of anionic surfactants, reduction of COD

Introduction

Domestic water demands in private households vary with different boundary conditions such as regional, country and cultural effects, consumer behaviour, etc. Figure 1 shows the different domestic water demand in different countries worldwide.

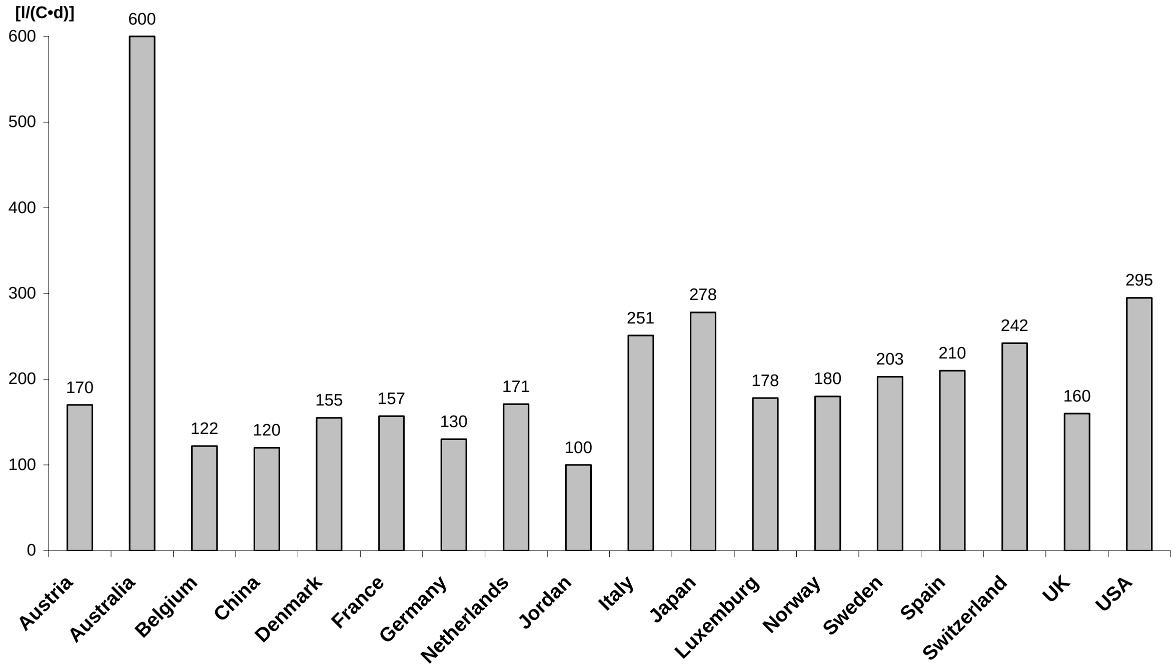

Figure 1: domestic water consumption in different countries (data from various references)

The consumption of drinking water in private households can be classified into four main groups: *toilet flushing*, *drinking and cooking*, *household cleaning* i.e. bathing, shower, clothes washing, hand washing, and dish washing, *other household uses* i.e. household cleaning, garden irrigation, car washing etc.. Among these four groups there are at least two, for which no drinking water quality is required, and can be replaced by service water i.e. treated waste water (better treated grey water).

Grey water is generally defined as waste water collected from indoor sources other than toilet, such as showers, bathtubs, hand basins and washing machines, and also from kitchens. Grey water light is defined as grey water without the discharge from kitchens, as it is known, that waste water from kitchens contains much higher concentrations of organic substance, oil and grease as well as phosphorus from dishwashing detergents. Though the actual amounts of grey water in various countries differ, the distribution on a percentage base among the different sources within the household does not differ much. Figure 2 shows that up to 56% of the water consumption in private households including dish washing is grey water, up to 50% grey water light.

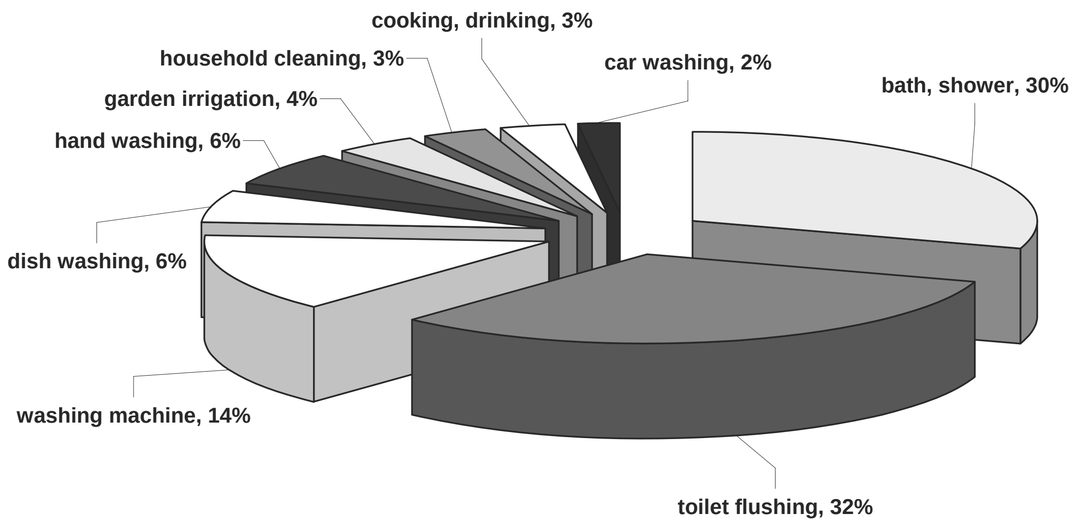

Figure 2: distribution of water consumption in percentage [Weber, 2004], modified

Regarding potential water reuse in households Figure 2 also shows that up to 40% of the domestic water consumption no drinking water quality is needed and these demands could be covered with service water (treated grey water), e.g. garden irrigation, toilet flushing, car washing, even household cleaning or washing machines (given certain service water quality). Ghisi et al (2006) reported a grey water reuse of up to 35% instead of portable water in Brazil.

General characteristics of grey water in private households (from literature data)

Since more than two decades grey water treatment and its potential reuse in different applications and/or different fields have attracted more and more attention. As the composition of grey water may differ widely due to different boundary conditions, only general characteristics can be defined. Table 1a and Table 1b show data on grey water characteristics, taken from diverse investigations (published after 2000) and considering highly variable boundary conditions. There have also been many investigations before the year 2000, and their data has been widely used as basis for later research projects. However, these sources are not mentioned in the tables. As the characteristics of grey water depend strongly on its origin Table 1a and 1b are subdivided accordingly.

Table 1a: grey water characteristics in different investigations (data from various references)

origin	literature	main parameters of grey water characteristics						
		quantity [L/(C·d)]	**COD [mg/L]**	**SS [mg/L]**	**E.Coli [/100 mL]**	**NH_4-N [mg/L]**	**N_{ges} [mg/L]**	**P_{ges} [mg/L]**
S	Okalebo, 2004 (Australia)	---	280 – 800	48 – 120	---	0,1-25	0,6-7,3	0,11-2,2
K	Chen, 2006 (China)	---	463 – 1,776	35 – 1,236	---	42-174	114-377	5,7-54,2
B, S, HW **(part of grey water light)**	Wilhelm, 2004 (Germany)	90	132 / 200	65 / 20	---	6,41	---	---
	fbr, 2005 (Germany)	70	150 – 400	35 – 70	---	4,0-16	---	0,5-4
	Laine, 2001 (UK)	---	367 – 587	58 – 153	2022 ± 5956	---	6,6-10,4	0,2-0,8
	Birks and Hills, 2005 (UK)	92,5	96,3	36,8	$3{,}9\times10^5$		4,6	< 4
	Prathapar et al. 2005 (Oman)	106	266	361	---	---	---	---
B, S, HW MW **(grey water light)**	Casanova et al 2001 (USA)	142	41-119,75	15-112	$3{,}2\times10^3$-$1{,}07\times10^7$	---	---	---
	fbr, 2005 (Germany)	70	250 – 430	---	---	---	---	---
	Chen, 2006 (China)	---	250 – 1,111	36 – 1,475	---	0,3-7,4	5,2-34	0,7-2,7
	Gross, 2006 (Israel)	100	702-984	85-285	9×10^4 - 10^8	0,1-0,5	25-45,2	17,2-27
	Hegemann, 2001 (Germany)	---	235	---	---	---	4,3	0,35
	McAdam, 2004 (UK)	100	< 490	< 177	< 151	---	---	---

Table 1b: grey water characteristics in different investigations (data from various references)

origin	literature	main parameters of grey water characteristics						
		quantity [L/(C·d)]	COD [mg/L]	SS [mg/L]	E.Coli [/100 mL]	NH_4-N [mg/L]	N_{ges} [mg/L]	P_{ges} [mg/L]
B, S, HW, WM, K **(grey water)**	Li et al., 2002 (Germany)	75	238 – 354	---	---	---	9,68-16,6	5,23-9,57
	Lazarova, 2001 (France)	---	471 – 951	71 – 215	$7{,}6\times10^5$ - $2{,}04\times10^7$	0,6-18,8	3,9-22,8	5-26,7
	Rosemarin, 2004 (Sweden) Zhu, 2006 (China)	82	400	200	---	25	---	5
	Oldenburg, 2005 (Germany)	63	421	---	---	---	---	5,3
	Lesjean et al, 2006 (Germany)	96	493	90	---	5,7	21	7,4
	Hegemann, 2001 (Germany)	---	554	10-17	3-4,8	---	10,0-17	3-4,8
HW	Hills et al, 2001 (UK)	2,7	60*	---	---	---	---	---
	Birks et al., 2004 (UK)		21 – 355	7 – 102	< $2{,}4\times10^6$	---	< 23,3	---
HW, K	Oldenburg, 2005 (Germany)	---	60-160	---	10^5	4,0-16	8,0-18	2,0-16
students in Uni.	Bi, 2005 (China)	200	40 – 120	28 – 130	---	0,3-2,3	---	0,06-0,14
	Jiang and Gao, 2003 (China)	---	120 – 220	80 – 120	---	17-25	---	---
synthetic grey water	Jefferson, 2001 (UK)	---	120-200	52-110	---	---	---	---
---	Dallas et al, 2004 (Costa Rica)	108	167*	96	$1{,}5\times10^8$	---	---	16

* BOD; --- = not mentioned; **B** = bath, **S** = shower, **HW** = wash basin, **WM** = washing machine, **K** = kitchen

The data given in Table 1a and 1b show the variation in COD concentrations depending on grey water amount and origin. As the objectives of the different projects listed above, varied, only four of the investigations covered all parameter groups, such as quantity, COD, SS and E.Coli., ammonium nitrogen, total nitrogen and total phosphorus.

Grey water from showers, bathtubs and wash basins, which is *only a part of grey water light* (B, S, HW, MW), shows COD concentrations of up to 500 mg/L. Grey water light, which is defined as discharge from bathtubs, showers, wash basins and washing machines, shows COD concentrations of up to 1,000 mg/L. The reason of these higher concentrations is the discharge from washing machines. COD concentrations of grey water (including kitchen waste water) are not – as expected – much higher than those of grey water light. Most of the investigations show values up to 1,000 mg/L.

In comparison of municipal wastewater grey water has a relatively lower concentration of nutrients (NH_4-N, total phosphorus). Regarding the nutrient ratio, part of grey water light and grey water light has a significantly low nutrient ratio, as grey water mostly has similar values as municipal wastewater.

Regarding the microbial load, grey water is not much “cleaner” than municipal waste water, E. Coli concentration of the latter mostly varying between 10^4 and 10^7 per 100 mL. However, light grey water shows a relatively lower level of E. Coli amount.

Methods

As part of the BMBF funded research project “semi-centralized supply and disposal systems for urban areas in China – part 2” (project code: 02WD0607) the investigation of wastewater treatment focuses on the treatment of grey water for potential reuse in urban areas in fast growing mega cities.

The pilot plant consists of a unit for preparation synthetic grey water, a pre-treatment unit with flocculation and micro-sieve (50 µm), two storage tanks for the five treatment units after the pre-treatment, one CONTIFLOW® sand filtration reactor (Hans Huber AG), two membrane biological reactors (ITT Flygt Pumpen GmbH, Hans Huber AG), one rotating ceramic membrane filtration unit, and one sequencing batch reactor (ITT Flygt Pumpen GmbH). The biological reactors are designed only for the carbon degradation because nitrogen and phosphorus degradations are not necessary by their low concentrations in grey water.

The data used in this study are based on the combination of Chinese statistics in Shanghai and Qingdao. Table 2 shows data on domestic water consumption in Chinese private households, classified into the different areas of usage. As domestic water demands in China vary highly in the different regions, the table lists the average values considering South and North China. The grey water, as shown in Table 2, amounts to 46 L/(C·d), including discharge from washing machines but without discharge from kitchen.

Table 2: Chinese domestic water consumption (GBT 50331-2002)

usage	**quantity [L/(C·d)]**
shower/bathing	37
washing machines	9
cleaning	7
kitchen	27
toilet flushing	37
drinking	3
sum	**120**

The physical and chemical composition of grey water in private households depends highly on the consumption of hygiene and cleaning products. As there are no data available for China, Table 3 shows data based on the statistics of the IKW (Industrieverband Körperpflege und Waschmittel e.V. = German Cosmetic, Toiletry, Perfumery and Detergent Association) and the Federal Statistical Office Germany. Regarding different cultural and consumer habits consumption in China would be lower than in Germany.

Table 3: consumption of hygiene products in private households (IKW, 2005)

product	quantity	
toothpaste	2,53	mL/(C·d)
shower gel	3,05	mL/(C·d)
soap (fluid and solid)	0,34	g/(C·d)
oil, lotion	0,26	mL/(C·d)
shampoo	4,63	mL/(C·d)
bubble bath	1,81	mL/(C·d)
washing powder	15,15	g/(C·d)
other washing agent	10,14	g/(C·d)
softener	0,22	g/(C·d)

Surfactants, used in washing agents to achieve better cleaning effects, basically have the same portions in recipes worldwide. Since 2000, the wash products are also phosphorus-poor products on the Chinese market after the exemption of the new production guidelines as it is internationally usual (Chang, 2005). Though additives for special cleaning effects are also added and may differ widely, they have no significant influence on the resulting grey water (Henkel, 2005). The surfactants mainly used are anionic surfactants, which belong to the group of linear alcylbenzenesulfonate (LAS). With generally used recipes the concentration of anionic surfactants can be expected to be more than 150 mg/L. Though their biological degradability is more than 99%, high concentrations in grey water may lead to disturbances in mechanical and biological treatment facilities, such as extensive unit as well as mechanical treatment unit will be disturbed by strongly over-foaming, adhesion on reactors, bio-fouling of membrane surfaces etc. The calculated concentration of non-ionic surfactants is about 40 mg/L, of cationic surfactants about 10 mg/L. Non-ionic and cationic surfactants affect probably oxygen transfer of the biological treatments. Figure 3 shows some pictures with over-foaming in test running of the pilot plant in different treatment units.

Figure 3: over-foaming by test running in pilot plant in Darmstadt-Eberstadt

Regarding limit values for surfactants in grey water, the Chinese standard for water reuse (GB 50336-2002) gives a LAS concentration of max. 1 mg/L. This leads to the necessity of treating grey water either physically, chemically or biologically in order to eliminate excessive LAS concentrations, which in turn has influence on the size of treatment facilities. There are two mechanical methods for reducing surfactants in grey water, (1) flocculation with sedimentation or filtration and (2) flotation with or without flocculation.

For the laboratory tests the method of flocculation with sedimentation was chosen in order to get principal optimization data for the pilot plant. Two test series were carried out, using two different flocculants (Al and Fe) and two different polymers (P1 and P2). The difference between the two polymers is their molecular weight, with P1 having a higher molecular weight, leading to a lower polymer dosage.
Dr. Lange cuvette tests were used for laboratory tests to simplify the complications of DIN methods, for COD test LCK 314 and for anionic surfactant tests LCK 332. Geick et al. 1999 reported that the LCK 332 tests for anionic surfactants use acid/alkaline extraction according to methylene blue index (DEV H23, 1989 and DIN: EN 903, 1994). A comparison of the analytical results with the norm methods is not always possible through the simplification of sample preparations by the cuvette tests. A partly good compliance of both measurement methods had been shown at a municipal wastewater treatment. The cationic and anionic surfactants, that refine ion pairs in water, possibly can't be detected through these cuvette tests without further sample preparations (Geick et al. 1999).

Results

Figure 4 shows the results for test series 1 (using Al and P1), the COD reduction and the reduction of anionic surfactants. The combination of Al dosage of 30 mg/L and P1 dosage of 50 mg/L leads to a COD reduction of 79% and a reduction in anionic surfactants of 93%. In comparison, the combination of 40 mg/L Al and 40 mg/L P1 achieves a COD reduction of 79% and an anionic surfactants reduction of 95%. Thus, these two dosage variations are almost identical.

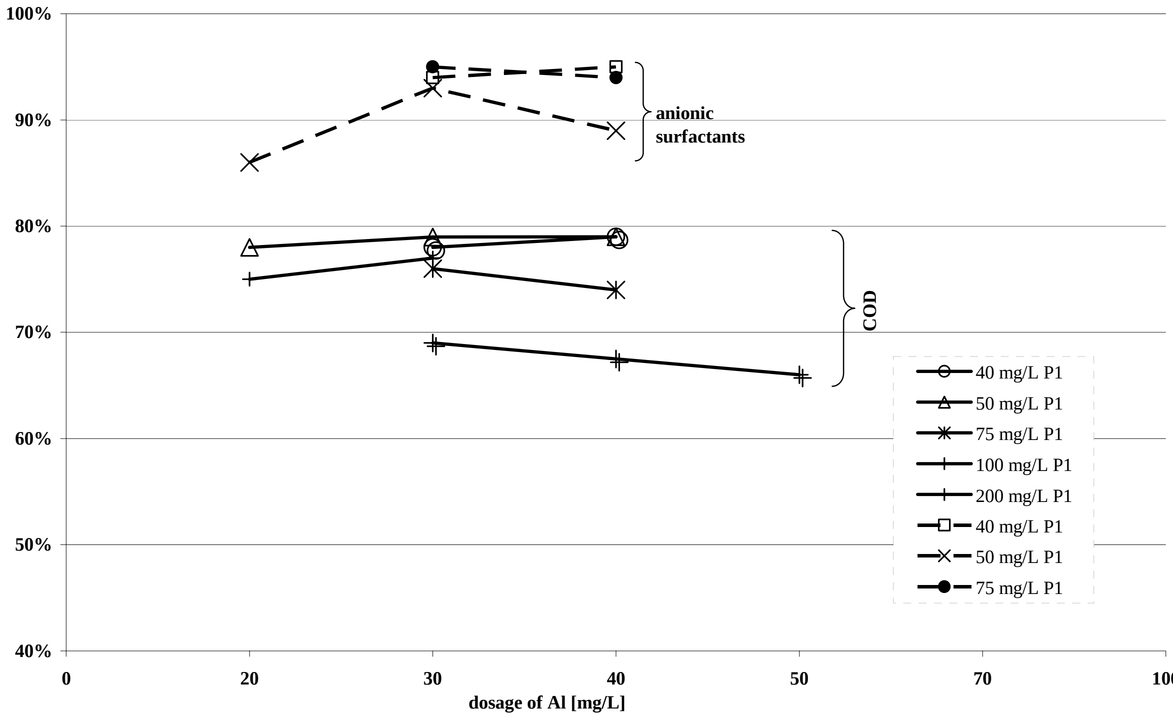

Figure 4: reduction of COD and anionic surfactants [%] in flocculation tests using different dosage combinations of flocculant (Al) and P 1

Figure 5 shows the results for test series 2 (using Fe and P1), the COD reduction and the reduction of anionic surfactants. The combination of Fe dosage of 50 mg/L and P1 dosage of 100 mg/L leads to a COD reduction of 78% and a reduction in anionic surfactants of 95%. The same results are achieved with the combination of 60 mg/L Fe and 100 mg/L P1. In comparison with test series 1 (using Al and P1), the dosage of Fe has to be significantly higher than with Al to reach the same reduction rates, thus leading to higher operation costs. Furthermore, as a negative result of flocculation with Fe and P1, the pH decreases.

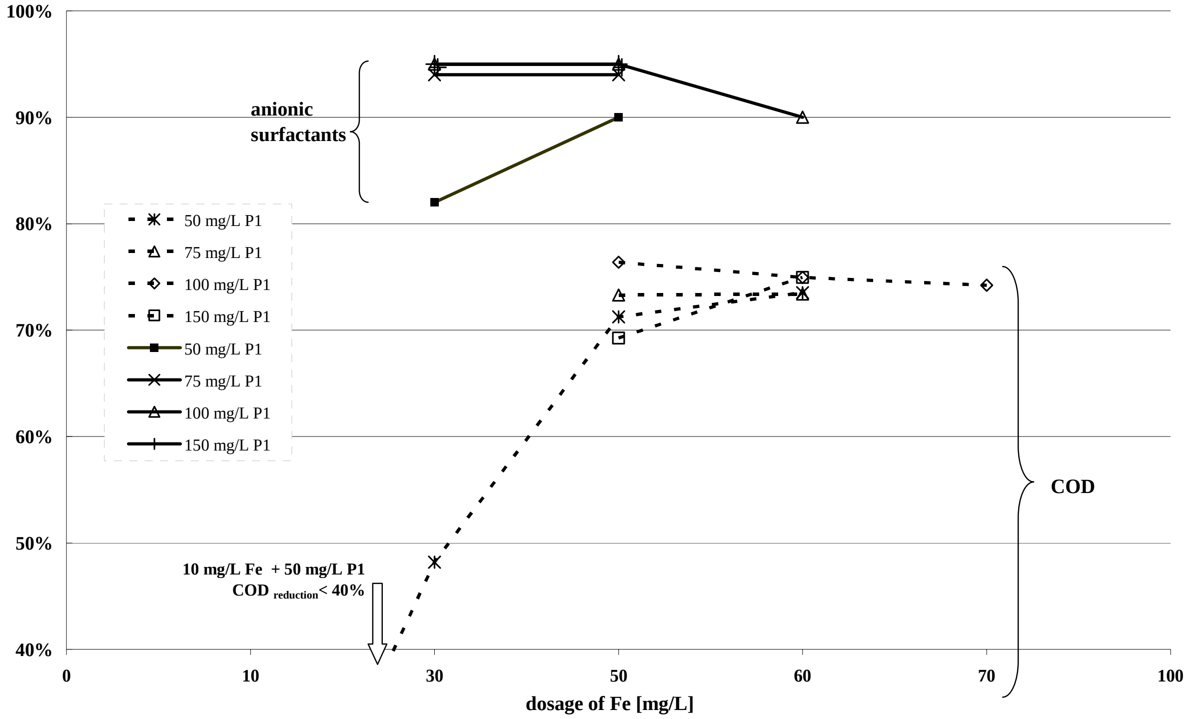

Figure 5: reduction of COD and anionic surfactants [%] in flocculation tests using different dosage combinations of flocculant (Fe) and P1

Polymer P1 was used in the test series described above to generally investigate surfactant removal. As it is not produced in Europe, another test series was carried out, this time using a different polymer (P2). P2 has similar characteristics as P1; it is available in Europe and will be used in the pilot plant. This series was set up in order to optimize the polymer dosage.

Figure 6 and Figure 7 shows the results of the test series for (1) COD reduction and (2) reduction of anionic surfactants, using 40 mg/L Al and 60 mg/L Fe as flocculant and different dosages of P2.

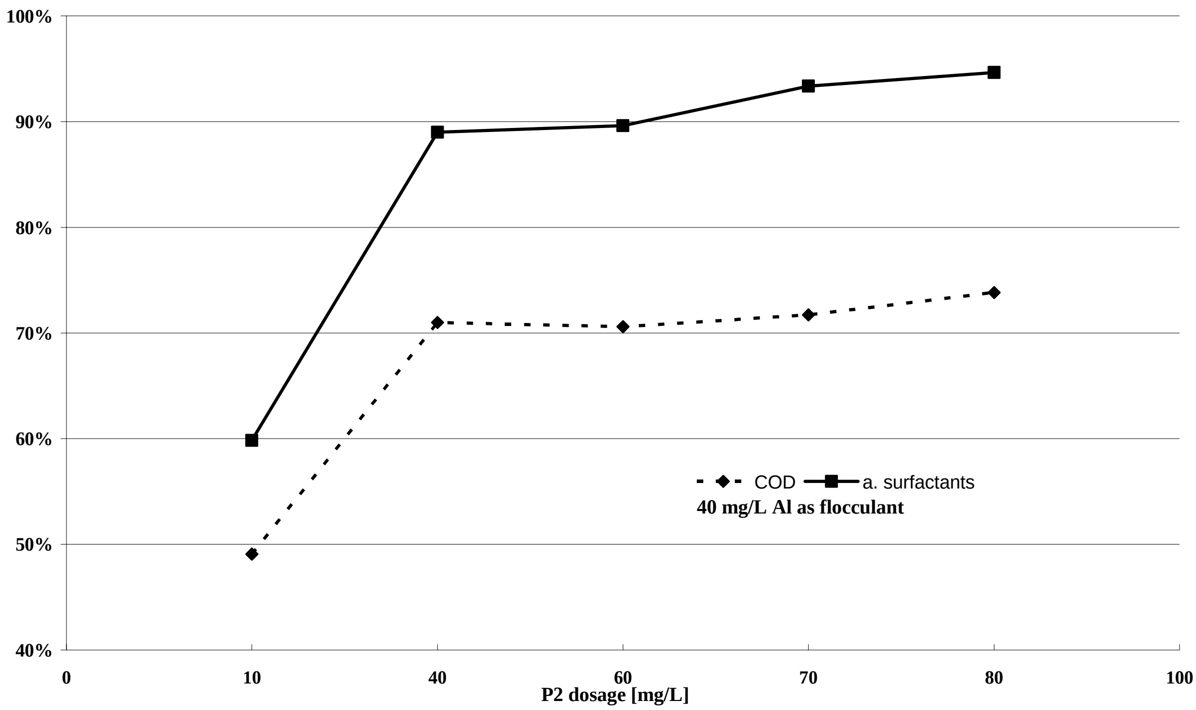

Figure 6: reduction of COD and anionic surfactant concentrations [%] after flocculation with 40 mg/L Al and different dosages of P2

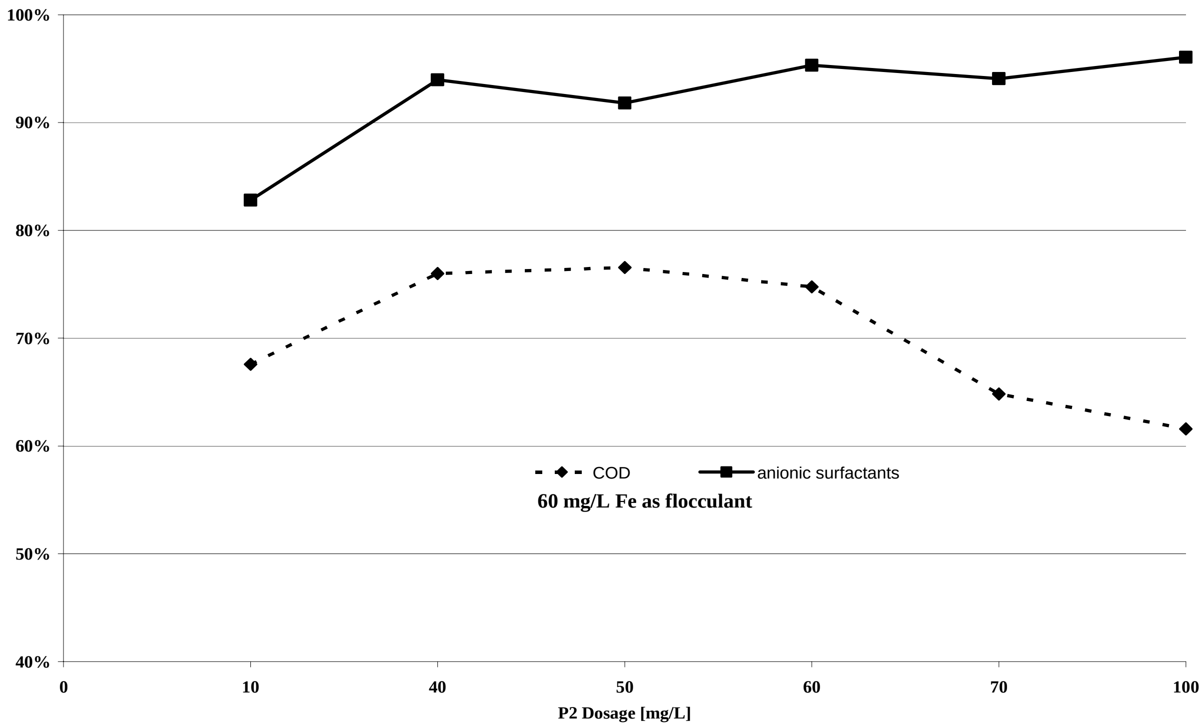

Figure 7: reduction of COD and anionic surfactant concentrations [%] after flocculation with 60 mg/L Fe and different dosages of P2

The COD concentrations were reduced up to 70%. Starting with a COD concentration of about 450 mg/L, the COD after flocculation will be no higher than 150 mg/L. With respective P2 dosage the reduction of anionic surfactants reaches more than 90%. Starting with a surfactant concentration of about 160 mg/L, the surfactants will be no higher than 15 mg/L. These concentrations are comparable to influent concentrations between 5 and 20 mg/L of anionic surfactants in municipal wastewater treatment plants (Geick et al. 1999).

Conclusion and Perspectives

The reduction of concentration of COD and anionic surfactants has proved satisfactory. Via flocculation more than 70% of COD and more than 90% of anionic surfactants can be removed from raw grey water. This means, that the following biological treatment facilities can be dimensioned considering maximum COD concentrations of 200 mg/L. Furthermore, a low nutrient ratio (C: N: P) is to be expected in the grey water.

The laboratory tests have been executed following 30 minutes sedimentation instead of filtration with micro-sieve, which is now used in the pilot plant. The adjustment of flocculation to the filtration must be tested in the pilot plant since a filtration with micro-sieve (50 µm) has definitively other requirements of structure of flocks as sedimentation. This experience will be collected by running the pilot plant.

An alternative method for the pre-treatment of grey water is flotation instead of flocculation. Due to their physico-chemical characteristics the method of flotation is suitable for the elimination of anionic surfactants from grey water. Air is used instead of adding chemicals, needing specific air dosages and blower equipment. The surfactants could be reused in production facilities, disposed on landfill sites or can be incinerated. Surfactant removal from grey water will be further tested in the pilot plant.

Beside anionic surfactants there are also non-ionic and cationic surfactants in use, which have not been considered in this study, due to complex analysis methods. These surfactants, too, have great significance and may prove negative in grey water treatment.

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