Electronic Supporting Information

for

Development and Experimental Validation of the Composition and Treatability of a New Synthetic Bathroom Greywater (SynGrey)

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11 Pages, 7 Tables, 5 Figures

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1. Methods

Table S1. Fifty real greywater compositions for 20 water quality parameters, as reported in the literature. GW type indicates source, which was any combination of showers (S), baths (B), or washbasins (WB). Values represent the mean measurement for each study; except, GW #8 were the median measurement, GW #10, #29, and #30 were the midpoint, and GW#47 were single measurements.

#	pH	Turbidity (NTU)	EC (µS/cm)	TS (mg/L)	TSS (mg/L)	VSS (mg/L)	TDS (mg/L)	COD (mg/L)	TOC (mg/L)	TN (mg/L N)	NH_3 (mg/L N)	NO_3^- (mg/L N)	TP (mg/L P)	PO4 - (mg/L P)	$SO4^-$ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Cl^- (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	GW Type	Citation
1	7.24	28	1044		52	45		174	27	10.5		1.21		0.62	157	57	33		125	18.7	S, WB	[1]
2					115		68	328			1.13	5.07		11.0							S, WB, B	[2]
3	7.14	10.9	443	165	16.1		140	50					0.218					42.3			WB	[3]
4	7.2	26.5	327		36.8			96.3					0.86								S, B, WB	[4]
5	7.45	25.5	544	470	67.8		413				1.67	0.85		3.86		91.1	19	22.7	37.5	6.4	S, B	[5]
6	7.37								24.6												S	[6]
7		150	468		125			399		9.48			0.424								S, B, WB	[7]
8	7.25	150	166		84						7.5		0.955			5.7	1.85	13.5	12.7	3.35	B, S	[8]
9		32							44		8.4										S, WB	[9]
10	8.1				107			158.5		5	0.22	0.13	0.530			99.5	21.9		71.6	6.65	S, WB	[10]
11			1323	884		85		374	101		1			7				207	126		B, S, WB	[11]
12		33			43			158													S, B, WB	[12]
13	7.89	83.8	660	638	167		469	290			3			0.7		17.5	25.8		105		S, WB, B	[13]
14	7.91				58		806	86.1		12.2	7.2	0.226	1		222	96.6	50.5	149	95.2		S, WB	[14]
15	6.8	38.8	921		32.2			72.7	41												S, WB	[15]
16	7.5	62			42.2			252													B, WB, S	[16]
17	7.42	35.2	890	659	94		565	77		10.9			1.12			59.9	23	147	110		S	[17]
18	7.3	335		533	248		286	352.6	65.7			22.5				16.0	53.1		181	39.9	S, WB	[18]
19										5			1.37			47.9	5.29			5.79	S, B, WB	[19]
20					52.2			120.4													S, B, WB	[20]
21	7.47	101			100			451	72.6	8.73				0.11							S, B, WB	[21]
22	7.92		645		4.9			77.2		7.1			0.8								WB	[22]
23	7.6				33			102	32.6		6.7	0.2		3.5							S	[23]
24	7.49		897																		S	[24]
25	7.62		571																		S	[24]
26	7.62	19.2			32.2			151	61.2												S	[25]
27	7.6	20			42			171	58	11.4											B, WB	[26]
28	7.6	29	645					109			11.8	0	1.6	1							S	[27]
29								150		7.5			0.4								B, S	[28]
30								373													S	
31	7.36	143					355	194					1.33					81			S, WB	[29]
32		35						144		7.6	0.7	3.9		0.16							S, B, WB	[30]
33		42						575		16.4	1	7.5		0.42							S	[30]
34	7.4	375	1400	683	353	133	330	294.3								15.8	56.1		184	43.1	S	[31]
35	7.1	133	1500	817	505	347	312	58								19.7	21		149	5.54	WB	[31]
36	7.5	35.3	1600		29.8		599	170			2.7	0.67		0.03	58	79.6	47.6		106	10.4	S	[32]
37					216			370													S, WB	[33]
38	7.7	68	1267					302		23			3								S, WB	[34]
39	6.9			326	58	43		197			8.6		1.3								S	[35]
40	6.3	55			70			291		22			4.1								S	[36]
41	8.4	54			75			278		25			4.1								B	[36]

#	pH	Turbidity (NTU)	EC (µS/cm)	TS (mg/L)	TSS (mg/L)	VSS (mg/L)	TDS (mg/L)	COD (mg/L)	TOC (mg/L)	TN (mg/L N)	NH_3 (mg/L N)	NO_3^- (mg/L N)	TP (mg/L P)	PO4- (mg/L P)	SO4- (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Cl^- (mg/L)	Na^+ (mg/L)	K^+ (mg/L)	GW Type	Citation
42	7.6	92		631	76		559	424	104		1.56	0.9		1.63							B, S	[37]
43	8.1	102		558	40		520	433	40		0.53	0.34									WB	[37]
44	6.13				81			445													S, WB	[38]
45	7.03	33.5	214		57	43		196	41.8		4.7		0.49	0.25							S, WB	(This Study)
46		19.6			29			87													S, B, WB	[39]
47					29			86	49												WB, B, S	[40]
48	6.52		237					374		11.6		0.69		0	17			27.9			S	[41]
59	7.7	35.8						146													WB	[42]

Table S2. Bench-scale coagulation jar test mixing conditions.

Simulated process	Mean velocity gradient, G (s^{-1})	Mixer speed (rpm)	Mixing time (min)
Rapid mix	600	290	1.0
Flocculation 1	50	55	10
Flocculation 2	10	20	10
Sedimentation	0	0	30

2. Results

2.1. Bathroom Greywater Quality Comparison

Table S3. Distribution of water quality values expected for real bathroom greywater composition, as determined from 49 different real bathroom greywater compositions reported in the literature (Table S1). The SynGrey values were measures experimentally except shaded cells which were calculated based on ingredients. SD is standard deviation.

Parameter	Real Bathroom Greywater Composition (distribution of values from literature data)				SynGrey
	Median	25th	75th	n	Mean±SD
pH	7.47	7.22	7.62	35	7.43±0.29
Turbidity (NTU)	38.8	30.5	96.3	31	39±7
EC (µS/cm)	653	462	1100	20	779±18
TS (mg/L)	631	502	671	11	609
TSS (mg/L)	58	37.6	98.5	34	67±17
TDS (mg/L)	441	326	561	12	521
VSS (mg/L)	67.8	44.0	109	7.00	44±14
COD (mg/L)	184	112	346	42	159±34
TOC (mg/L)	46.5	40.3	64.6	14	54.9
TN (mg/L)	10.7	7.58	13.3	16	8.9
Ammonia (mg/L N)	2.7	1.0	7.2	17	3.6±0.3
Nitrate (mg/L N)	0.77	0.25	3.23	14	0.66
TP (mg/L P)	1	0.53	1.37	17	0.88
Phosphate (mg/L P)	0.66	0.19	3.03	14	0.48
SO4 (mg/L)	108	47.8	173	4	156
Ca (mg/L)	52.5	17.1	82.5	12	18
Mg (mg/L)	24.4	20.5	48.3	12	22
Cl (mg/L)	61.7	26.6	148	8	116
Na (mg/L)	108	89.3	131	12	91
K (mg/L)	6.65	5.79	18.7	9	6

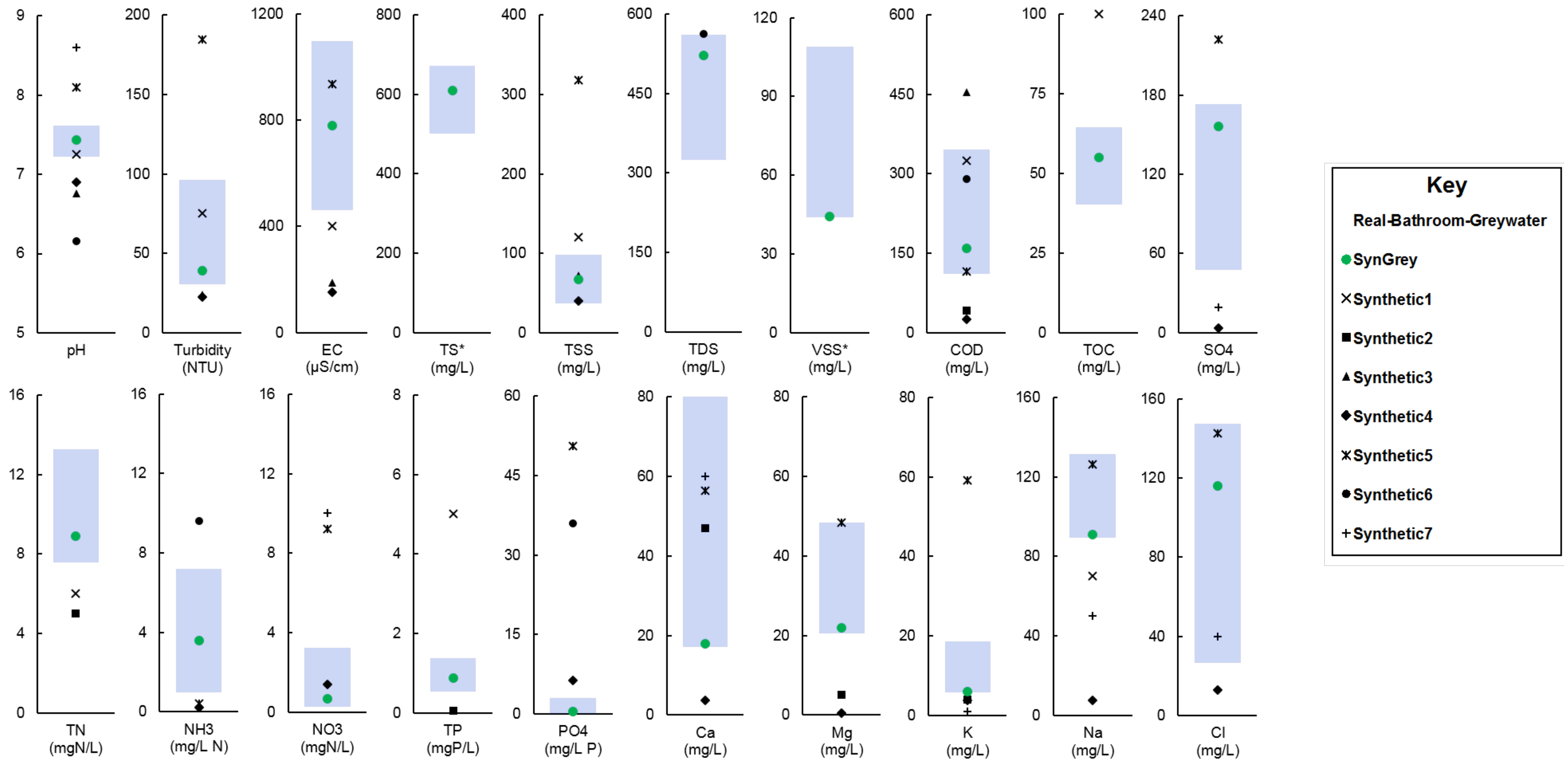

Figure S1. Comparison of synthetic greywater recipes with the 25th to 75th percentile range of real bathroom greywaters (Table S3) for 20 water quality parameters. Citations for the mean values for each synthetic recipes were: New Synthetic (SynGrey), 1 = [43], 2 =[19], 3=[44], 4= [45] low concentration, 5= [45] high concentration, 6= [46], 7= [47]. For synthetic recipes 4 and 5, values for all ions, except nitrate and phosphate, were calculated based on ingredients since they were not measured experimentally. For synthetic recipe 1, commercial ingredients (shampoo, conditioner, etc.) are used, and an expect ranges of TSS, COD, etc. were given. This analysis used midpoints from those ranges. *None of the other synthetic recipes reported values for this parameter.

Table S4. Average values for the ratios of total chemical oxygen demand (COD) to soluble COD (COD:sCOD) as reported for real bathroom greywaters in the literature (Table S1).

GW#	COD (mg/L)	sCOD (mg/L)	COD:sCOD
10	148	86	1.7
11	423	250	1.7
12	158	110	1.4
13	211	108	2.0
37	170	106	1.6
49	374	129	2.9
		Median	**1.9**

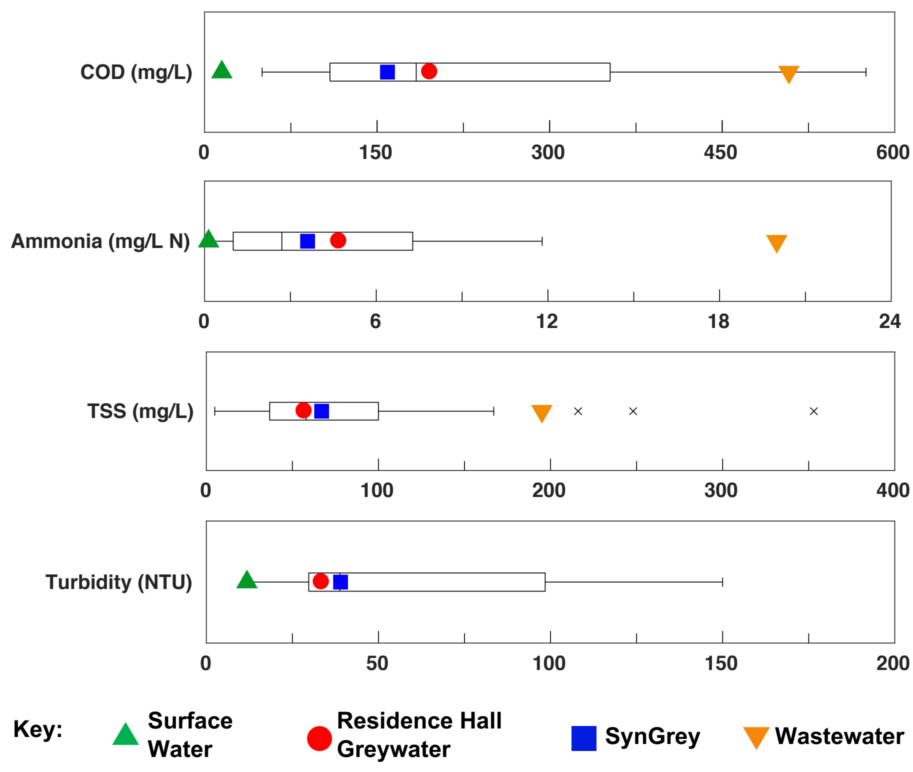

Fig. S2. Boxplots of real bathroom greywater literature data for COD (n=42), ammonia (n=17), TSS (n=34), and turbidity (n=31). Each boxplot has a different scale. Blue squares represent means of SynGrey for COD (n=12), ammonia (n=15), TSS (n=7), turbidity (n=19), pH (n=26), and phosphate (estimated). Red circles represent means of residence hall bathroom greywater for COD (n=35), ammonia (n=19), TSS (n=8), and turbidity (n=77). Data for the other 16 water quality parameters are in Table S3 and Figure S1.

2.2. Total Chlorine Demand and Decay Kinetics

Table S5. Statistical comparison of total chlorine residuals (mg/L Cl_2). There were 15 samples of each greywater.

Time (hr)	RH Greywater	SynGrey	p-value
0.5	12.5±4.6	16±1.4	0.48
1	10.5±4.6	12.7±1.4	0.60
2	8.2±4	10.8±1.6	0.56
4	6.5±3.6	7.7±1.5	0.77
8	4.5±2.7	6.3±1.5	0.55
24	2.9±2.2	3.6±1.7	0.79
48	1.8±1.1	3.5±1.8	0.43
72	1.5±0.8	3.4±1.3	0.22
120	1.1±0.5	2.1±1.3	0.46

Table S6. Chlorine demand values for both the RH Greywater and SynGrey. There were 15 samples of each water.

Chlorine demand	RH Greywater	SynGrey
1-hr Cl demand (mg/L Cl_2)	30.4±4.6[a]	28.1±1.5[a]
24-hr Cl demand (mg/L Cl_2)	37.7±2.2[a]	37.2±2.1[a]

In Table S7, outliers, identified graphically using normal probability plots, were omitted to improve the normality of the data. The RH Greywater had one sample that was a statistical outlier, with high total chlorine residuals at 8 to 48 hours. SynGrey had three samples that were outliers due to low C_w values. All first-order chlorine decay model parameter values were statistically similar between SynGrey and the RH Greywater whether or not these outliers were included in the analysis (Table S7 and Table S2). However, omission of the outliers reduced the standard deviation of the SynGrey C_w such that it was no longer statistically similar to the additional real bathroom greywater value.[47]

Table S7. Statistical similarity table of parameters of chlorine parallel first-order decay model, with outliers omitted. Values are reported as mean ± standard deviation. Same letters indicate statistical similarity ($p>0.05$).

Parallel First-order Decay Model Parameter	RH Greywater	SynGrey	Additional Real Bathroom Greywater
Number of samples	14	12	14
Immediate chlorine demand, Cw (mg/L)	23±6[a]	23±2[a]	9±2[b]
Fraction decaying rapidly, x (%)	76±14%[a]	70±12%[a]	34±6%[b]
Rapid decay rate, k1 (hr^{-1})	1.1±0.9[a]	0.43±0.16[a]	1.3±0.4[a]
Slow decay rate, k2 (hr^{-1})	0.016±0.011[a]	0.0093±0.085[a]	0.05±0.02[a]

2.3. Bathroom Greywater Biodegradability

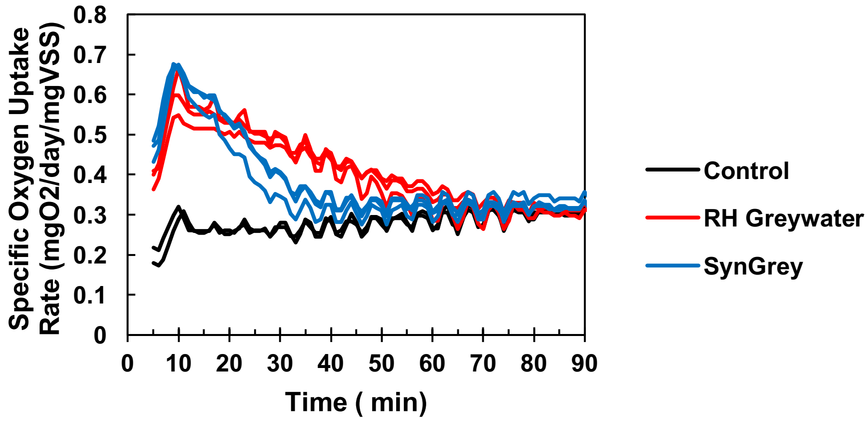

Figure S3. All replicates of the SOUR experiment.

2.4. Bathroom Greywater Coagulation

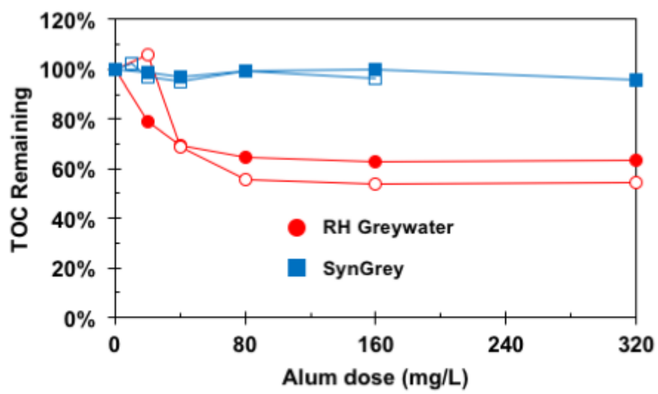

Figure S4. Total organic carbon (TOC) removal during alum coagulation for the RH Greywater and SynGrey. Turbidity data is in Figure 5. TOC percent remaining is normalized by the control (0 mg/L alum jar). Hollow and filled symbols indicate replicate samples of each greywater on different days.

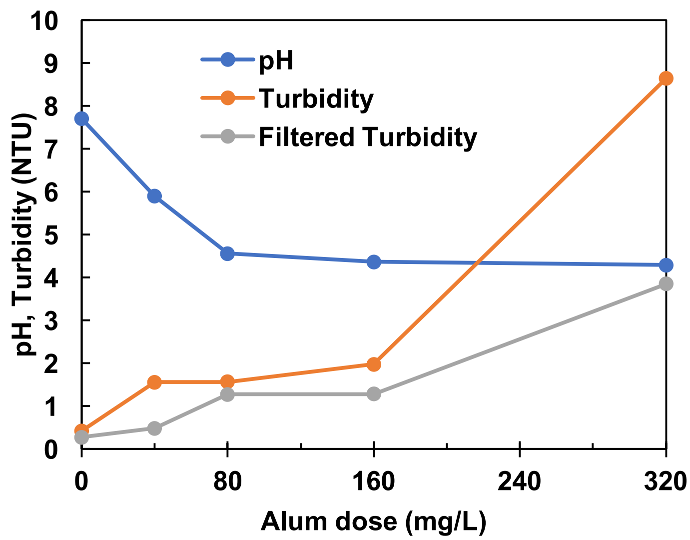

Figure S5. Alum coagulation of a deionized water solution with 49 mg/L yeast extract and 31 mg/L of sodium bicarbonate.

Turbidity in SynGrey rose steeply from an alum doses of 40 mg/L to 80 mg/L, and continued to rise until the turbidity at 160 mg/L and 320 mg/L exceeded the turbidity at 0 mg/L by approximately 8 NTU (Fig. 5a). The filtered turbidity at an alum dose of 20 mg/L was around 0.75 NTU and then at higher alum doses rose steadily to about 3.5 NTU at the 160 mg/L alum dose (Fig. 5b). These rises in turbidity were greater than could be explained by charge reversal and resuspension alone. To explain this phenomenon, experiments were run with individual ingredients of SynGrey.

A solution was made of deionized water with 49 mg/L yeast extract (the same concentration as in SynGrey) and 31 mg/L sodium bicarbonate to reach an alkalinity of 18 mg/L, approximately equal to the alkalinity in the SynGrey. This solution was then dosed with alum (doses from 0 to 320 mg/L) and allowed to coagulate, flocculate, and settle with the same procedure and measurements used for all other samples (e.g., Section 2.4.4 and Table S2). The effluent turbidity and filtered turbidity rose steadily in response to the alum addition. This rise in turbidity is expected to be caused by precipitation or complexation between the yeast extract and the alum. At the 320 mg/L alum dose, the effluent turbidity of the coagulated yeast extract solution was 8.6 NTU, and the filtered turbidity was 3.9 NTU. Based on these values, precipitate particles formed between the yeast extract and the alum can account for the majority of the rise in filtered turbidity seen during the SynGrey coagulation experiments. The rise in the total turbidity for SynGrey coagulation appears to a combination the formation of these alum-yeast extract particles as well as charge reversal and resuspension, which is expected to be mostly by kaolin. The modified SynGrey with higher alkalinity had a much less steep rise in turbidity and filtered turbidity from 40 to 320 mg/L alum doses (Fig. 5a and 5b), suggesting that high alkalinity can reduce or prevent this precipitation phenomenon.

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