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11 APPENDICES

The following list is a summary of information provided in Appendix A to Appendix H:

11.1 Appendix A: T_r measurements: surface and bubble aeration plant data

Table 11-1 Long-term T_r variation data

WCW 1

Module 1: surface turbine aeration			
05 July 2006	Temp @ 08h30	Temp @ 09h45	Temp @ 13h00
Stage 1 North	12.5	12.9	13.4
Stage 1 South	12.6	12.9	13.4
Stage 2 North	11.5	11.6	12.1
Stage 2 South	11.9	11.8	12
average	12.1	12.3	12.7

Module 2: submerged diffuser bubble aeration			
05 July 2006	Temp @ 08h30	Temp @ 09h45	Temp @ 13h00
North DO 1	17.7	17.8	18
South DO 2	17.7	17.8	18
North DO 3	17.6	17.7	17.9
South DO 4	17.8	18.0	18.3
North DO 5	17.6	17.7	18
South DO 6	17.7	17.7	17.9
average	17.7	17.8	18.0

Module 3: submerged diffuser bubble aeration			
05 July 2006	Temp @ 08h30	Temp @ 09h45	Temp @ 13h00
North DO 1	17.5	17.6	17.8
South DO 2	17.9	18.0	18.2
North DO 3	17.8	17.8	18
South DO 4	17.6	17.7	17.9
North DO 5	17.8	17.9	18.2
South DO 6	17.6	17.7	17.9
average	17.7	17.8	18.0

Module 1: surface turbine aeration			
28 October 2006	Temp @ 08h30		Temp @ 12h00
Stage 1 North			
Stage 1 South			
Stage 2 North	20.6		20.5
Stage 2 South	20.5		20.5
average	20.6		20.5

Module 2: submerged diffuser bubble aeration			
28 October 2006	Temp @ 08h30		Temp @ 12h00
North DO 1	22.8		23
South DO 2	22.6		22.8
North DO 3	22.8		23
South DO 4	23.1		23.4
North DO 5	23.4		23.6
South DO 6	23		23.1
average	23.0		23.2

Module 3: submerged diffuser bubble aeration			
28 October 2006	Temp @ 08h30		Temp @ 12h00
North DO 1	22.3		22.5
South DO 2	22.5		22.7
North DO 3	22.6		22.9
South DO 4	23		23.3
North DO 5	22.5		22.8
South DO 6	22.5		22.7
average	22.6		22.8

WCW 2

Module 1: surface turbine aeration		
26 June 2006	Temp @ 08h00	Temp @ 17:20
leg 1 DO1	14.4	15.2
leg 2 DO2	14.2	
Aerator out	14.1	
RAS return	14.2	
Clarifier 1 out	14.2	
Clarifier 2 out	14.1	
average leg 12	14.3	15.2

Module 2: surface turbine aeration		
26 June 2006	Temp @ 08h00	Temp @ 17:20
leg 1 DO1	14.2	14.7
leg 2 DO2	13.8	
Aerator out	13.9	
RAS return	13.9	
Clarifier 1 out	13.8	
Clarifier 2 out	13.8	
average leg 12	14	14.7

Pilot Plant: submerged diffuser aeration		
26 June 2006	Temp @ 08:00	Temp @ 17:20
Aerobic 6	9.7	16.6
Ambient	0.3	14.3

Module 1: surface turbine aeration		
27 October 2006	Temp @ 09h00	Temp @ 13:15
leg 1 DO1	21.7	22
leg 2 DO2	21.4	21.8
Aerator out		
RAS return		
Clarifier 1 out		
Clarifier 2 out		
average leg 12	21.6	21.9

Module 2: surface turbine aeration		
27 October 2006	Temp @ 09h00	Temp @ 13:15
leg 1 DO1	21.8	22.2
leg 2 DO2	21.5	21.9
Aerator out		
RAS return		
Clarifier 1 out		
Clarifier 2 out		
average leg 12	21.7	22.1

Remark:

WCW1 = plant 2

WCW2 = plant 1

WCW1a = plant 2 module 1

WCW1b = plant 2 module 2 and 3

WCW2a = plant 1 module 1 and 2

WCW2b = only on-line T_r data

WCW2c = plant 1 pilot

11.2 Appendix B: Raw sewage plant inflow diurnal temperature variation

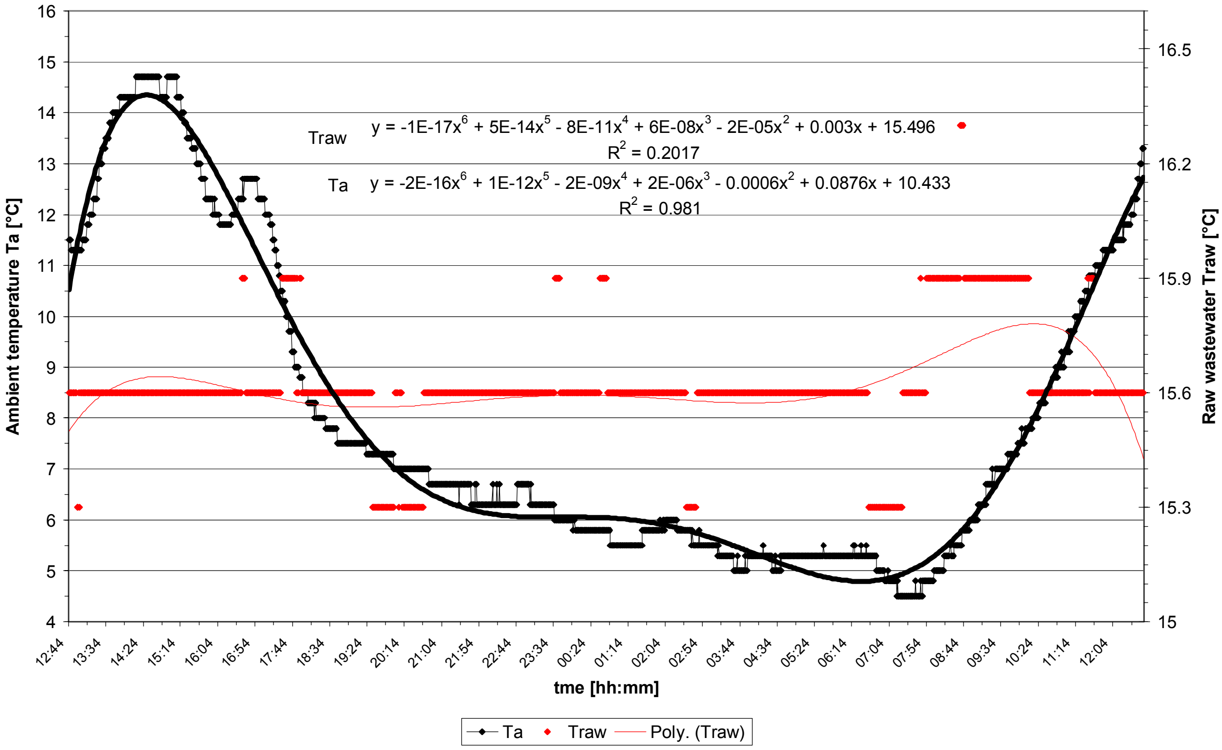


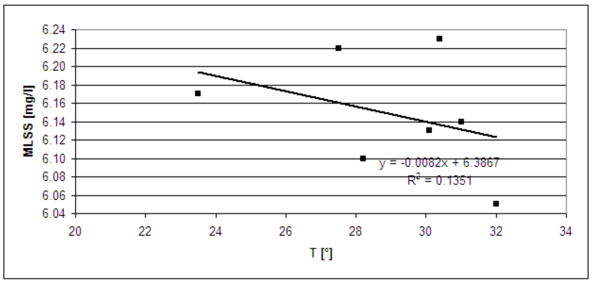
Figure 11-1 T_{raw} and T_a data points and diurnal profiles

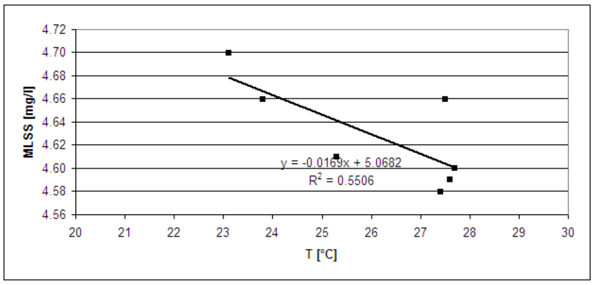
11.3 Appendix C: MLSS concentration meter reading T_s-based variations

Table 11-2 Test data: MLSS concentration meter reading variation with T_s

exp15-1-7a	time	T	MLSS	T Ambient
	13:53	23.5	6.17	22.1
	14:10	28.2	6.10	
	14:17	30.1	6.13	
	14:20	31.00	6.14	
	14:25	32.00	6.05	
	14:40	30.4	6.23	
	14:54	27.5	6.22	

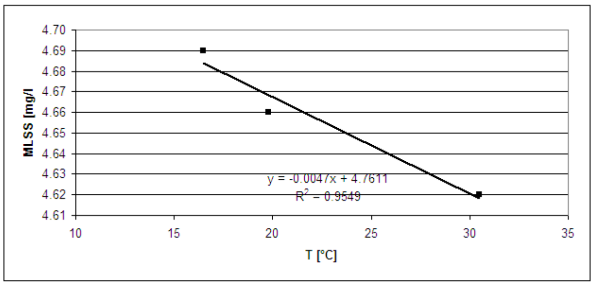
exp15-1-7b	time	T	MLSS
	13:53	23.8	4.66
	14:10	27.5	4.66
	14:17	27.4	4.58
	14:20	27.6	4.59
	14:25	27.7	4.60
	14:40	25.3	4.61
	14:54	23.1	4.70

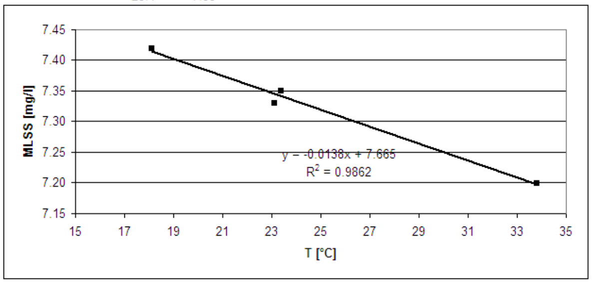




exp4-1-7	time	T	MLSS
	13:53	19.8	4.66
	14:13	30.5	4.62
	14:13	16.5	4.69

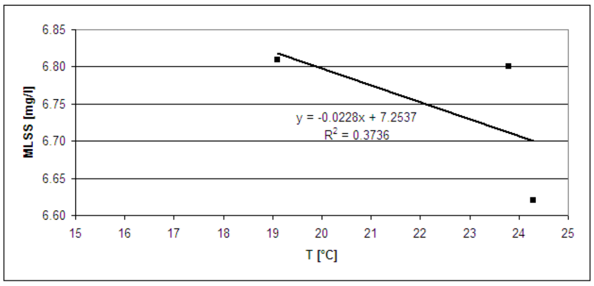
exp8-1-7a	time	T	MLSS
	14:00	23.1	7.33
		18.1	7.42
		33.8	7.20
		23.4	7.35

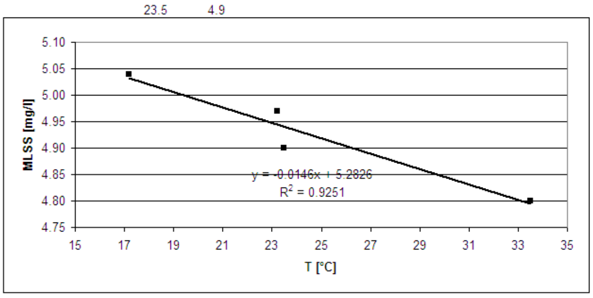




exp11-1-7	time	T	MLSS	T Ambient
	15:05	23.8	6.80	25.2
		24.3	6.62	
		19.1	6.81	

exp8-1-7b	time	T	MLSS
	14:00	23.2	4.97
		17.2	5.04
		33.5	4.80
		23.5	4.9





	temperature 1	temperature 2	MLSS 1	MLSS 2	change in MLSS
exp15-1-7a	15	25	6.26	6.18	-0.08 g/l
exp15-1-7b	15	25	4.81	4.65	-0.17 g/l
exp4-1-7	15	25	4.69	4.64	-0.05 g/l
exp8-1-7a	15	25	7.46	7.32	-0.14 g/l
exp11-1-7	15	25	6.91	6.68	-0.23 g/l
exp8-1-7b	15	25	5.06	4.92	-0.15 g/l
					-0.14 g/l over 10°C
					-0.014 g/l over 1°C
					-14 mg/l over 1°C

11.4 Appendix D: Batch MLSS settling data

Table 11-3 Summary of experimental batch settling test reactor zone conditions and results

Parameter	Statistics	Anaerobic	Anoxic	Aerobic 1	Aerobic 2	Aerobic 3	Aerobic 4
DO [mg/ℓ]	Average	0.09	0.07	2.34	2.90	1.91	2.94
	St. dev.	002	0.01	0.54	0.51	0.48	0.31
	n	29	29	29	29	29	29
T [°C]	Average	17.9	17.9	18.9	18.8	18.1	17.8
	St. dev.	1.2	1.3	1.3	1.2	1.3	1.3
	n	29	29	29	29	29	29
MLSS [mg/ℓ]	Average	3536	3531	3440	3415	3399	3382
	St. dev.	300	263	285	262	258	273
	n	35	35	35	35	35	35
SVI [mℓ/g]	Average	121	123	105	98	104	101
	St. dev.	31	30	12	9	12	11
	n	34	34	34	34	34	34
ISV [m/hr]	Average	2.1	1.9	1.8	2.1	2.0	2.1
	St. dev.	0.6	0.5	0.5	0.6	0.6	0.5
	n	34	34	34	34	34	34
Turb [FNU]	Average	140	98	60	44	31	30
	St. dev.	24	21	15	11	11	9
	n	34	34	34	34	34	34

Table 11-4 Batch MLSS settling sample extended cooling and heating

Temperature change	Position	T [°C] at 0 minutes	T [°C] at 30 minutes	SVI [mℓ/g]	SVI increase [mℓ/g/1°C]	ISV [m/hr]	ISV decrease [m/hr/1°C]	Turbidity [FNU]	Turbidity increase [FNU/1°C]
Cooled	Sun	8.6	16.1	131	-	0.53	-	15	-
Cooled	Shade	6.4	10.8	164	-6.2	0.04	0.09	7	1.5
Heated	Sun	29.0	27.3	106	-	1.76	-	33	-
Heated	Shade	25.5	25.3	106	0	1.76	0	21	6.0

Table 11-5 Batch settling test results data, with temperature and container size variation

Container	Condition & Temperature	SVI 19/6	SVI 21/6	SVI 19/7	SVI Ave	u 19/6	u 21/6	u 19/7	u Ave	Tur 19/6	Tur 21/6	Tur 19/7	Tur Ave
	MLSS [mg/ℓ]	4210	3930	4470	4203	4210	3930	4470	4203	4210	3930	4470	4203
1ℓ	Shade	181	170	172	174	0.00	0.09	0.04	0.04	14	19	9	14
	T30 [°C]	17.0	19.5	20.9	19.1	17.0	19.5	20.9	19.1	17.0	19.5	20.9	19.1
1ℓ	Sun	105	104	116	108	0.92	1.06	0.11	0.70	20	23	14	19
	T 30 [°C]	21.5	23.8	25.2	23.5	21.5	23.8	25.2	23.5	21.5	23.8	25.2	23.5
2ℓ	Shade	195	137	181	171	0.31	0.88	0.13	0.44	14	-	14	14
	T 30 [°C]	17.0	19.5	20.7	19.1	17.0	19.5	20.7	19.1	17.0	-	20.7	19.1
2ℓ	Cool, shade	-	164	-	164	-	0.04	-	0.04	-	7	-	7
	T 30 [°C]	-	10.8	-	10.8	-	10.8	-	10.8	-	10.8	-	10.8
2ℓ	Cool, sun	-	131	-	131	-	0.53	-	0.53	-	15	-	15
	T 30 [°C]	-	16.1	-	16.1	-	16.1	-	16.1	-	16.1	-	16.1
2ℓ	Heat, shade	-	106	-	106	-	1.76	-	1.76	-	21	-	21
	T 30 [°C]	-	25.3	-	25.3	-	25.3	-	25.3	-	25.3	-	25.3
2ℓ	Heat, sun	-	106	-	106	-	1.76	-	0.76	-	33	-	33
	T 30 [°C]	-	27.3	-	27.3	-	27.3	-	27.3	-	27.3	-	27.3
2ℓ	Dilute, shade	-	122	-	122	-	1.89	-	1.89	-	21	-	21
	T 30 [°C]	-	19.1	-	19.1	-	19.1	-	19.1	-	19.1	-	19.1
2ℓ	Dilute, sun	-	102	-	102	-	2.73	-	2.73	-	23	-	23
	T 30 [°C]	-	23.2	-	23.2	-	23.2	-	23.2	-	23.2	-	23.2
2ℓ	Sun	109	106	119	111	0.62	1.50	0.40	0.84	15	21	23	21
	T 30 [°C]	20.9	23.6	25.1	23.2	20.9	23.6	25.1	23.2	20.9	23.6	25.1	23.2
20ℓ	Sun	112	-	139	126	0.97	-	0.31	0.64	18	-	11	15
	T 30 [°C]	19.0	-	22.2	20.6	19.0	-	22.2	20.6	19.0	-	22.2	20.6

11.4.1 SVI variation

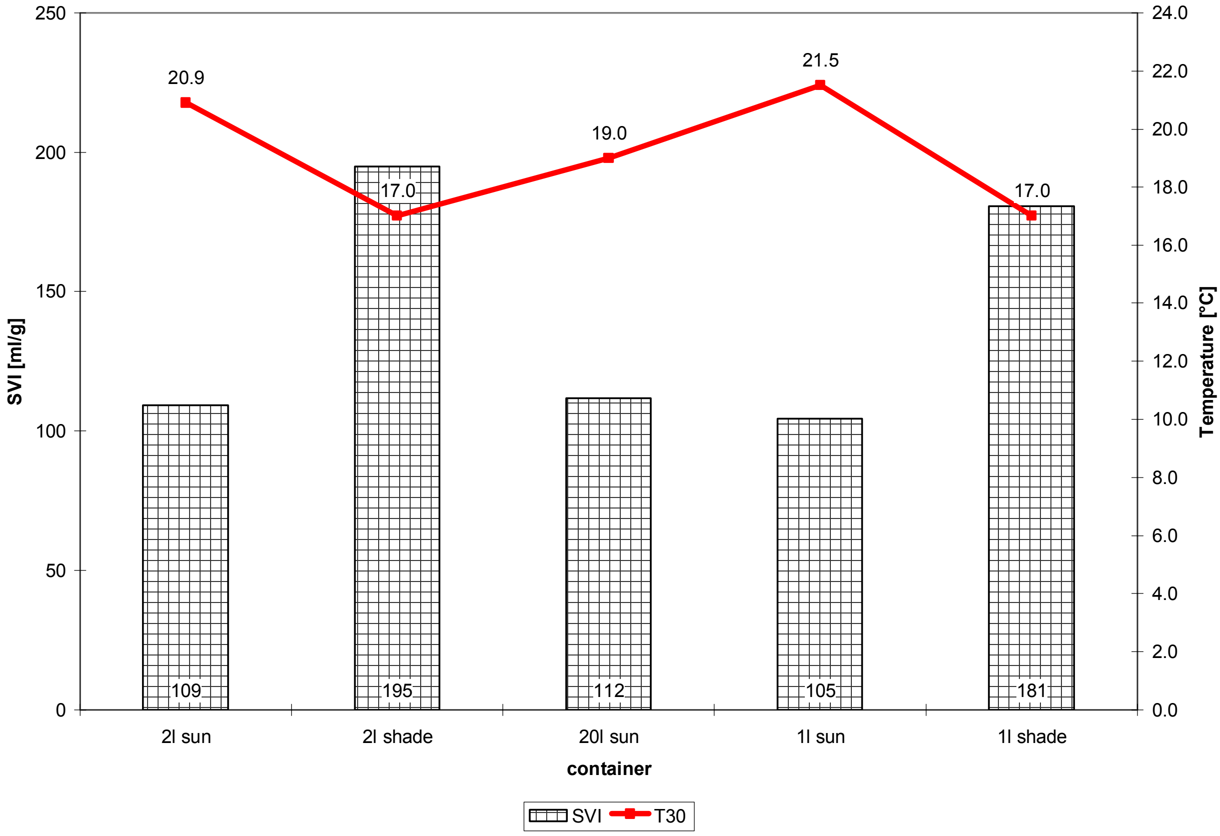


Figure 11-2 SVI, different containers, T_s after 30 min., MLSS 4210 mg/ℓ

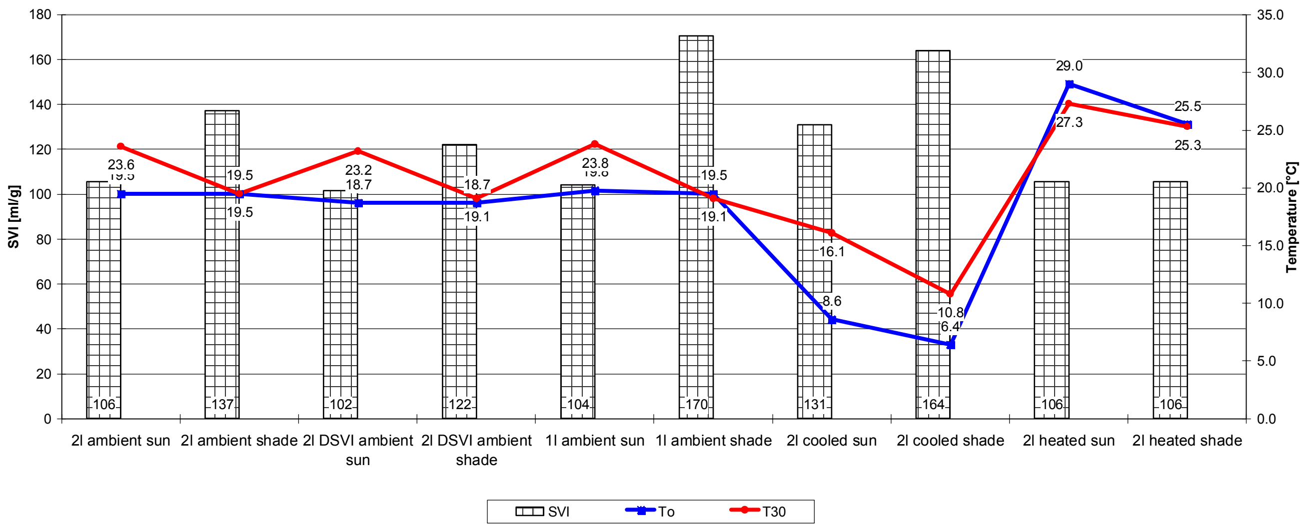


Figure 11-3 SVI, different containers, T_s after 0 and 30 min., MLSS 3930 mg/ℓ

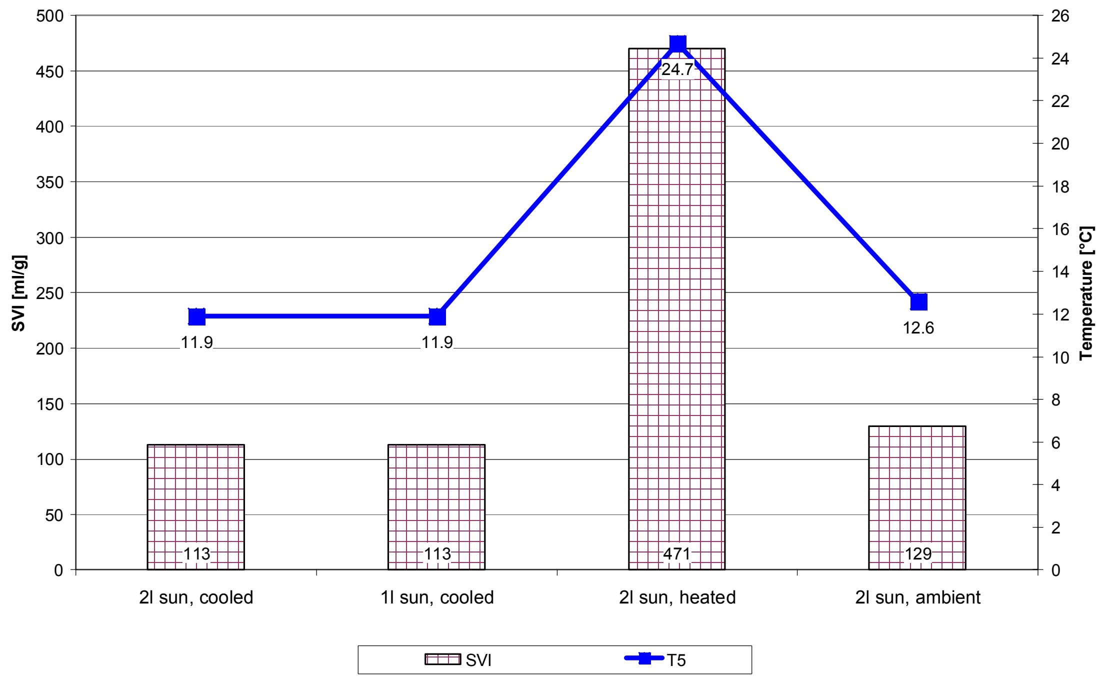


Figure 11-4 SVI, different containers, T_s after 5 min., MLSS 4250 mg/ℓ

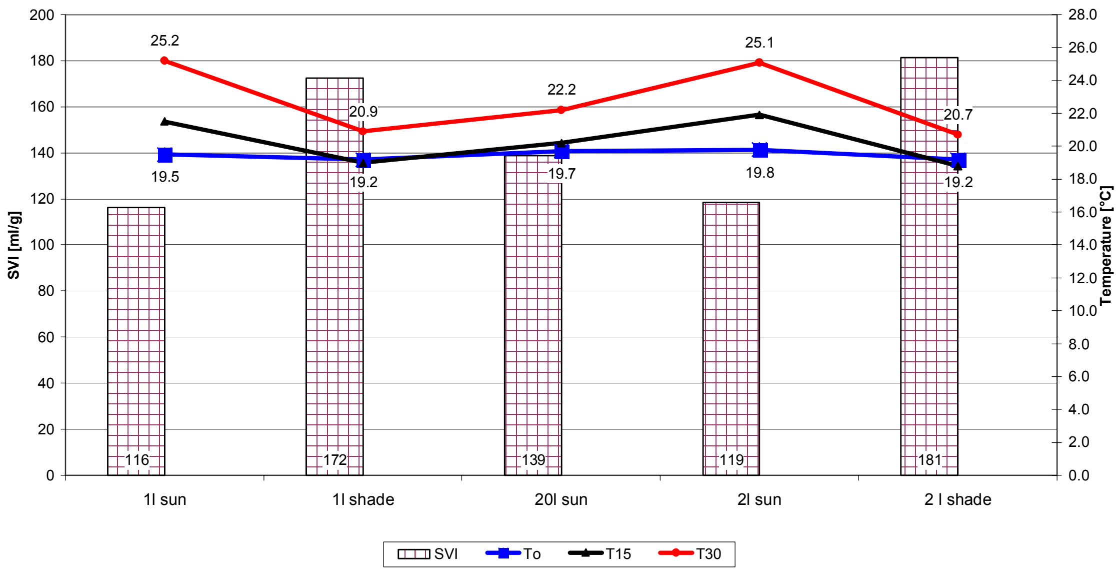


Figure 11-5 SVI, different containers, T_s after 0, 15 and 30 min., MLSS 4470 mg/ℓ

11.4.2 Zone settling velocity variation

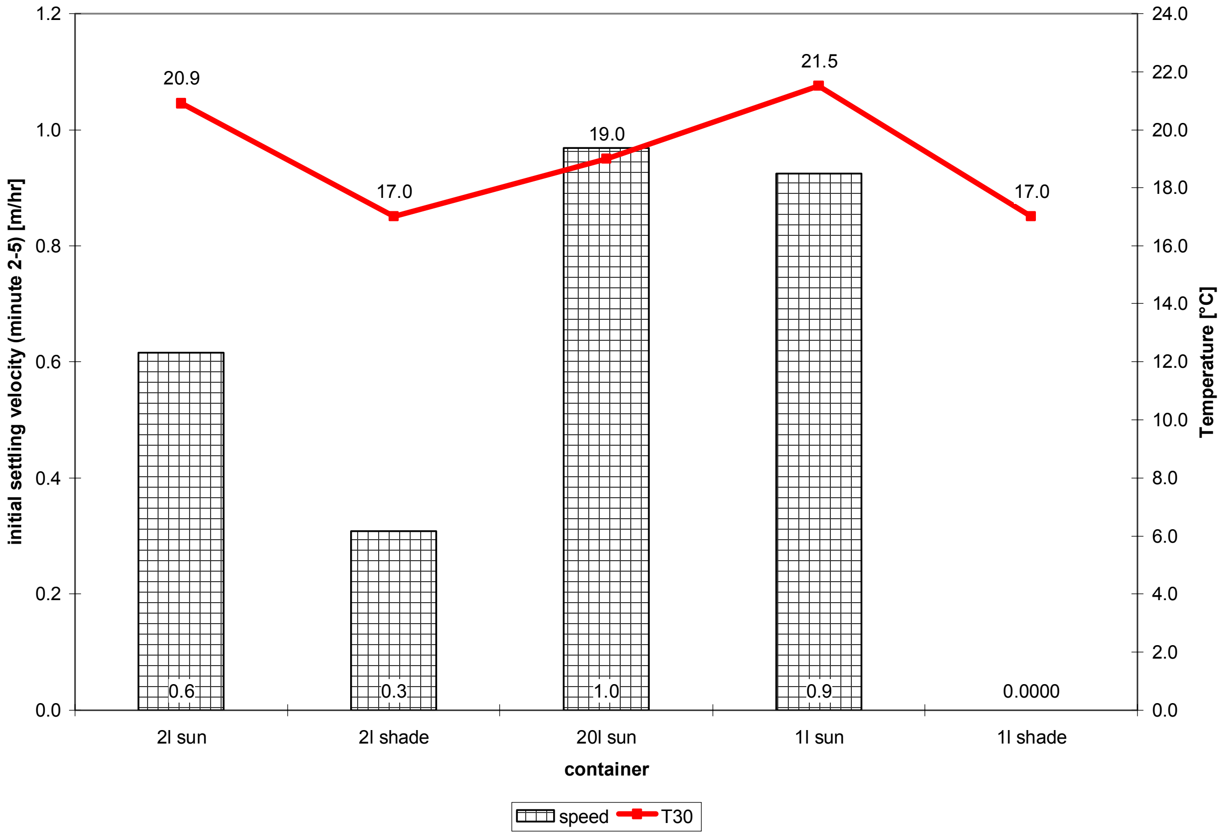


Figure 11-6 Initial settling velocity, T_s after 30 min., MLSS 4210 mg/ℓ

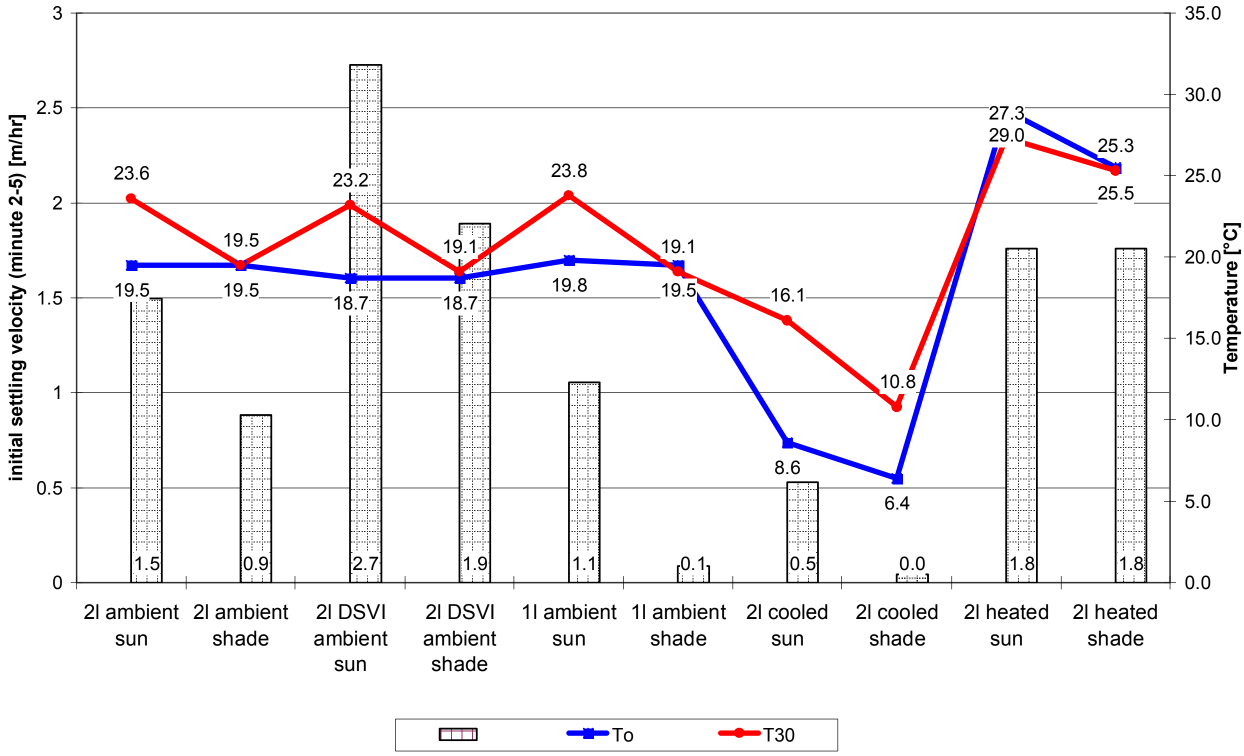


Figure 11-7 ISV, T_s after 0 and 30 min., MLSS 3930 mg/ℓ

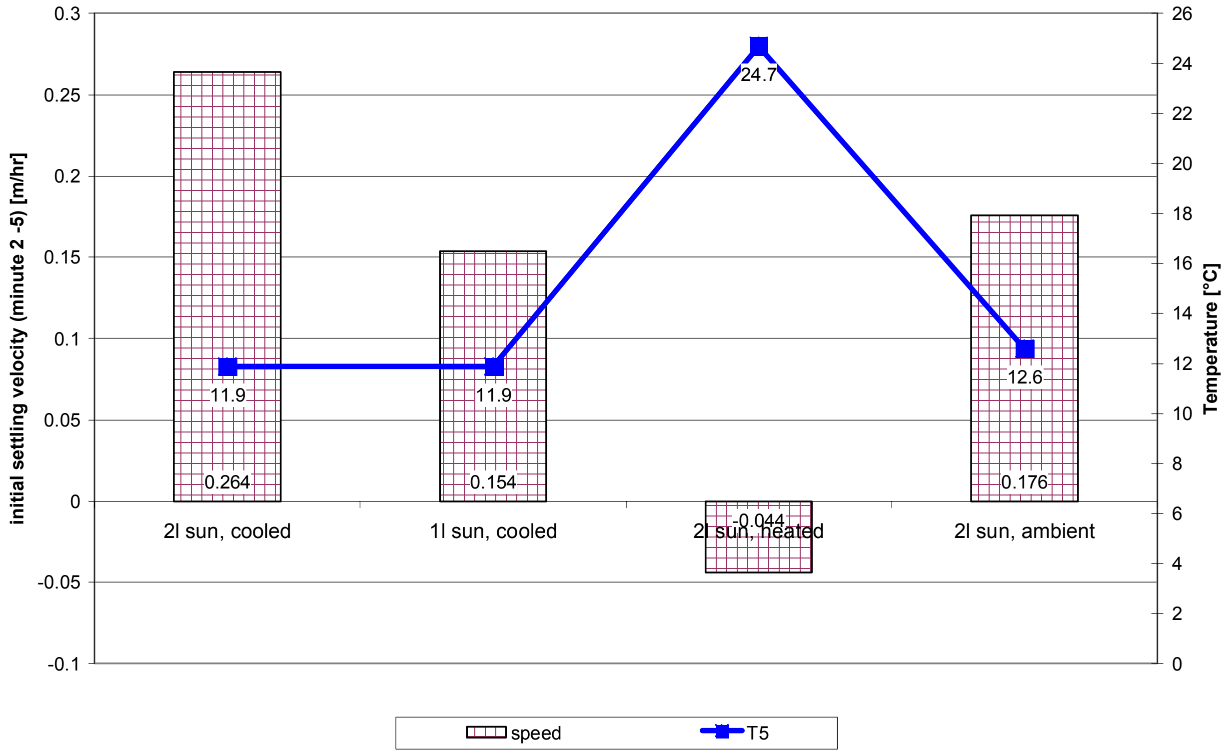


Figure 11-8 ISV, T_s after 5 min., MLSS 4250 mg/ℓ

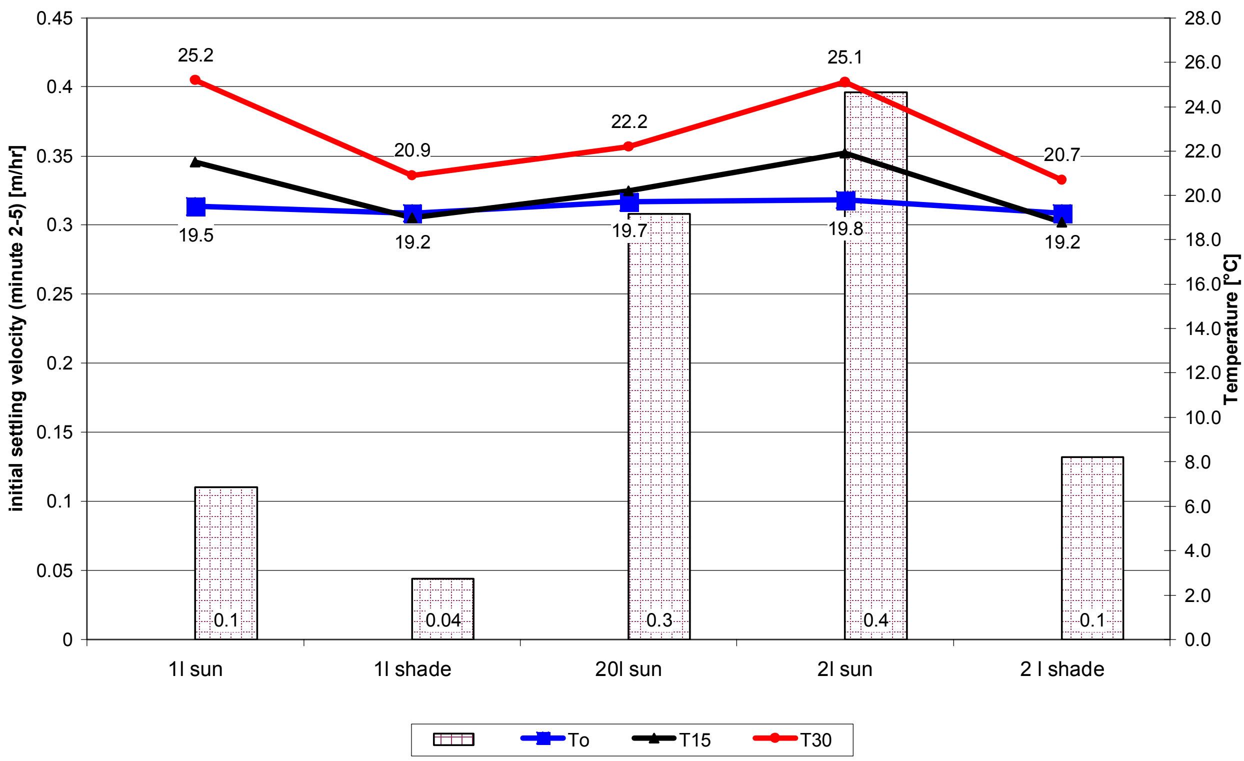


Figure 11-9 ISV, T_s after 0, 15 and 30 min., MLSS 4470 mg/ℓ

11.4.3 Turbidity variation

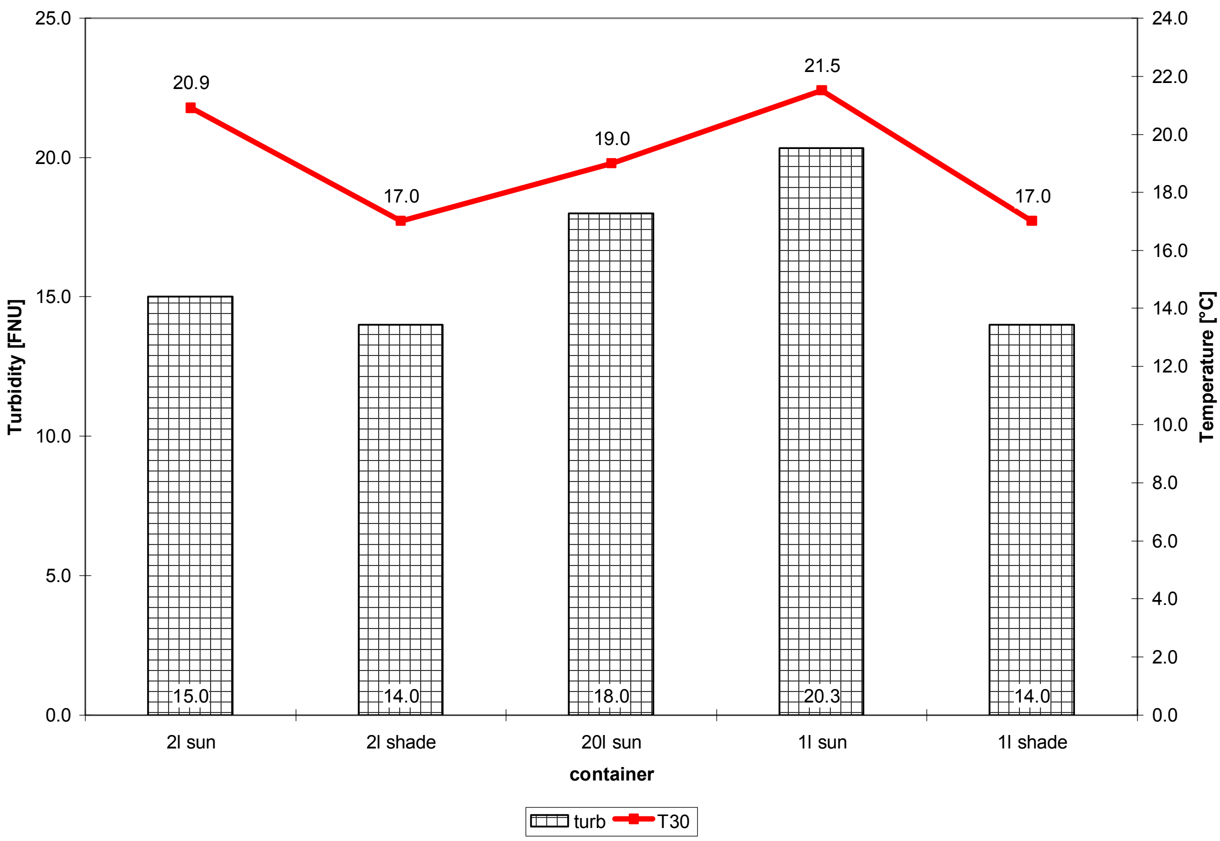


Figure 11-10 Turbidity, 30 min. settling, T_s after 30 min., MLSS 4210 mg/ℓ

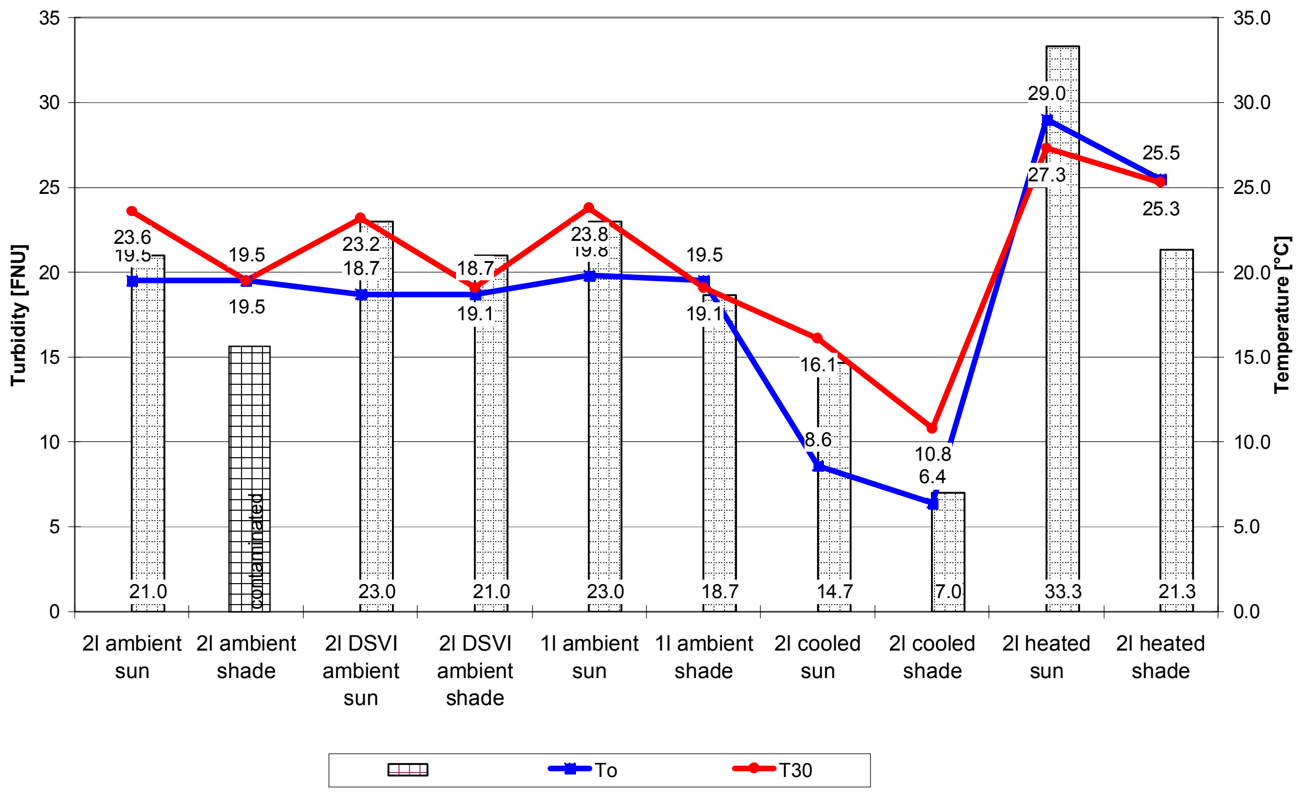


Figure 11-11 Turbidity, 30 min. settling, T_s after 0 and 30 min, MLSS 3930 mg/ℓ

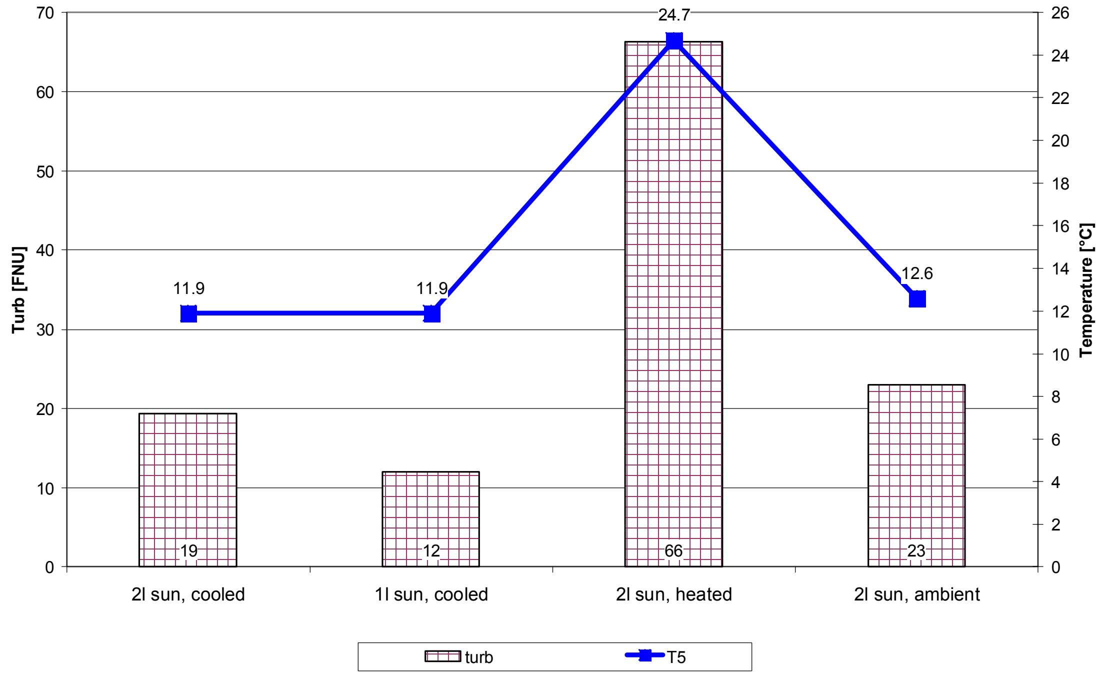


Figure 11-12 Turbidity, 30 min. settling, T_s after 5 min., MLSS 4250 mg/ℓ

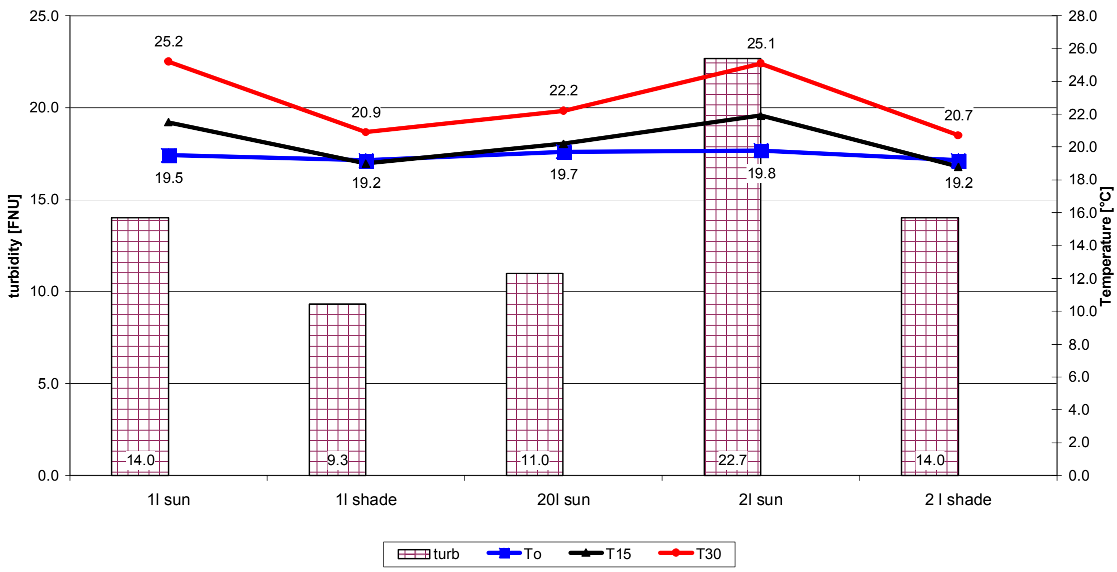


Figure 11-13 Turbidity, 30 min. settling, T_s after 0, 15 and 30 min., MLSS 4470 mg/ℓ

11.5 Appendix E: On-line meter data

An example of a typical Excel spreadsheet diagram with an original 12-hour profile of h and T_a logger data is provided in Figure 11-14. The T_a profile varies from about 5 to 25°C, whereas the 30-minute MLSS settling profiles final h value varies from about 359 mm to 210 mm. The period between each moving settling profile indicates the meter cleaning and standby cycle.

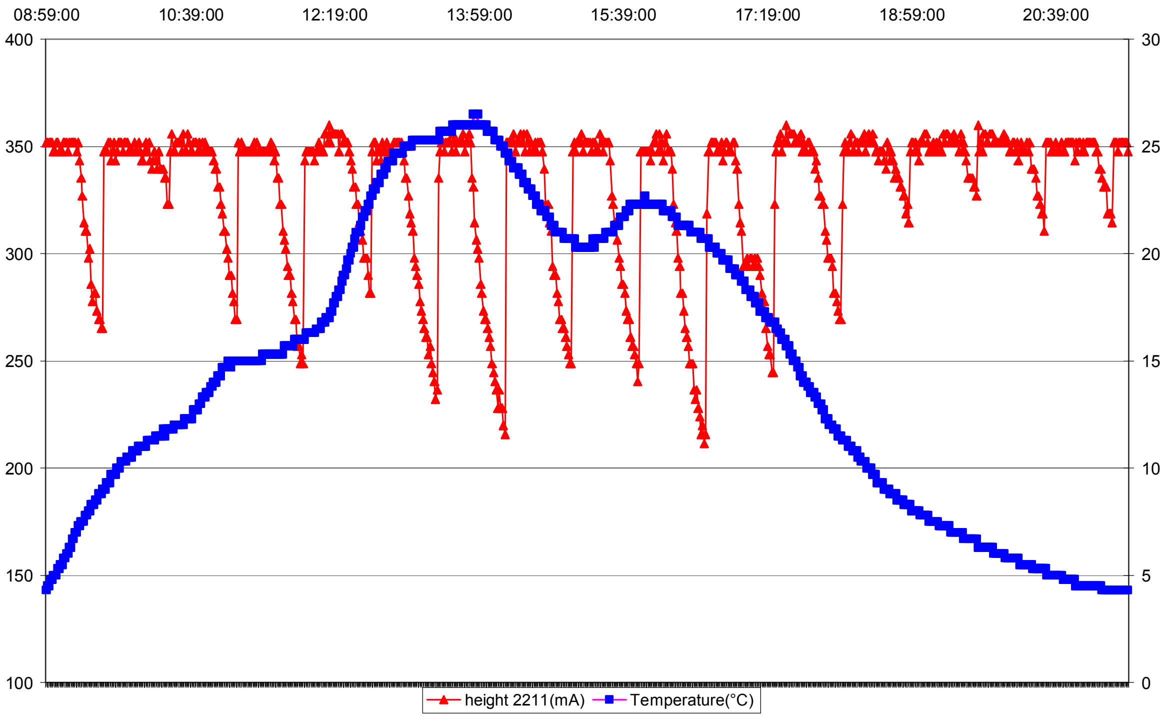


Figure 11-14 Consecutive 30-minute settling profiles from MLSS settling meter data, h and T_a readings over 12 hours

Table 11-6 Summary of on-line experimental data

Parameter	MLSS Concentration	u1	u2	u3	u4	u5	u6	T_r	T_a	h	SV_{30}	SVI	u_ave	u_max	t_umax
	[mg/ℓ]	[m/hr]	[m/hr]	[m/hr]	[m/hr]	[m/hr]	[m/hr]	[°C]	[°C]	[mm]	[mℓ/ℓ]	[mℓ/g]	[m/hr]	[m/hr]	[min.]
Average	4700	0.1	0.3	0.2	0.2	0.2	0.1	18.3	23.6	259	717	151	0.2	0.8	16.2
St. dev.	129	0.2	0.4	0.2	0.1	0.1	0.1	0.5	5.3	68	190	37	0.1	0.5	9.8
n	559	83	83	83	83	83	83	83	83	83	83	83	83	83	83

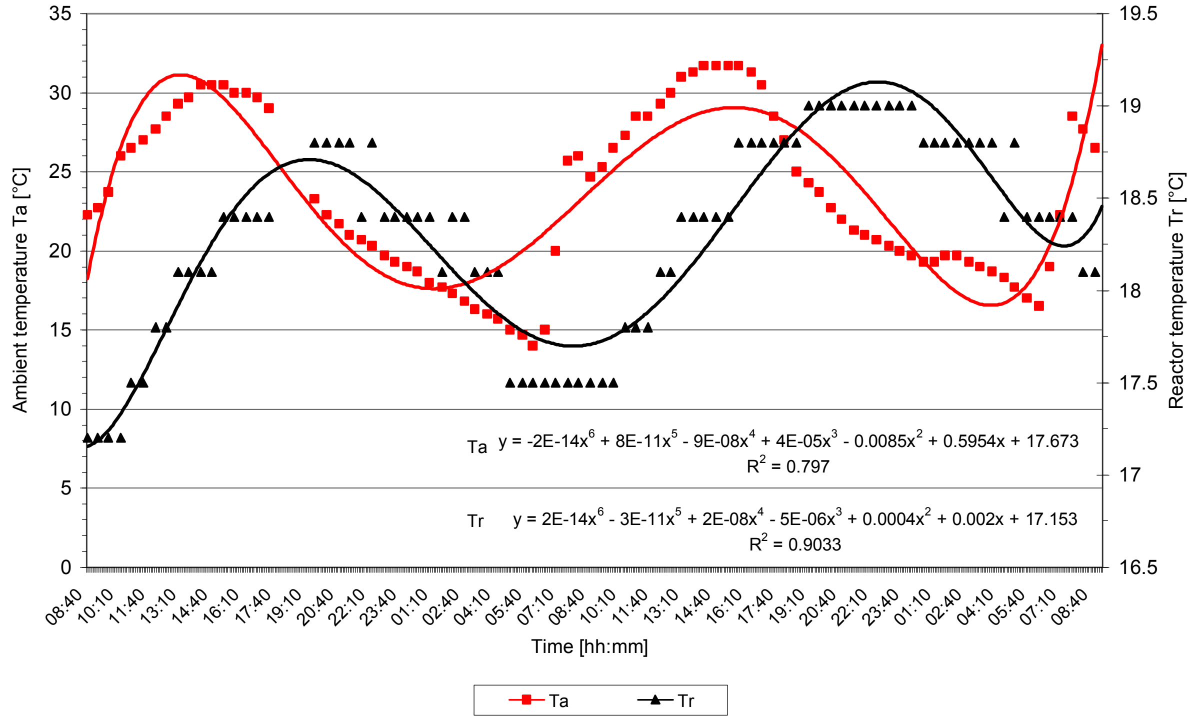


Figure 11-15 Two-day T_a and T_r profiles

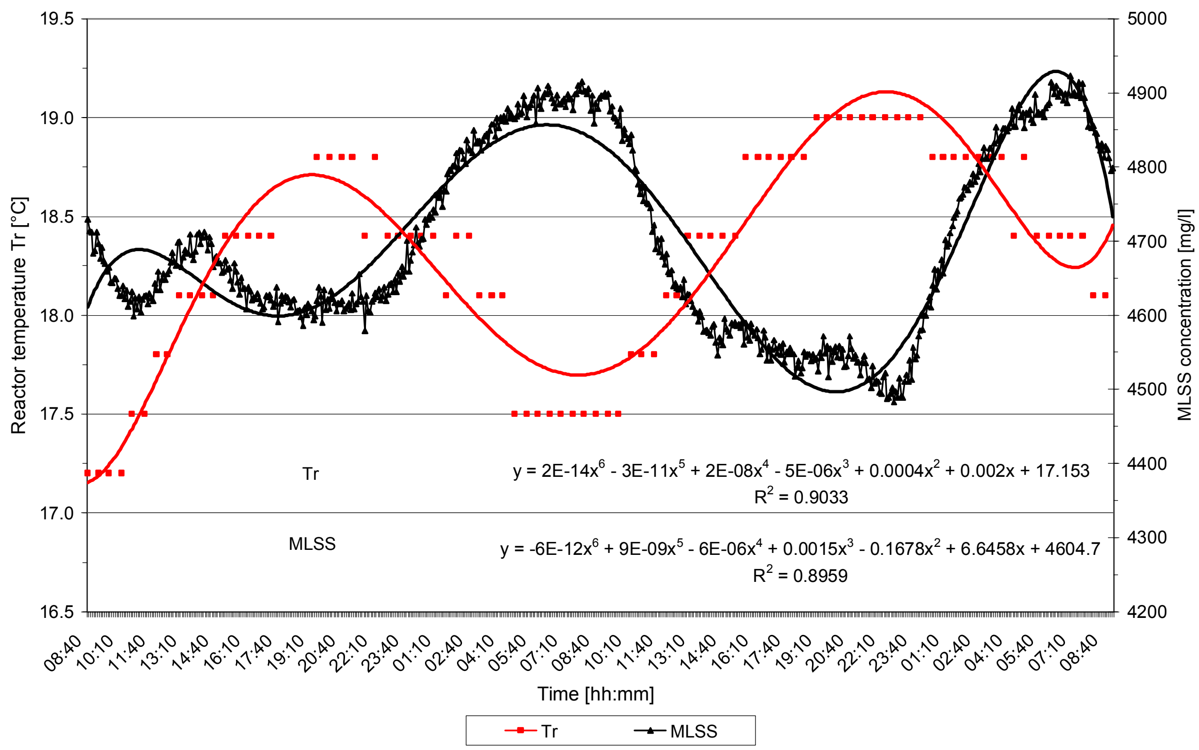


Figure 11-16 Two-day T_r and MLSS concentration profiles

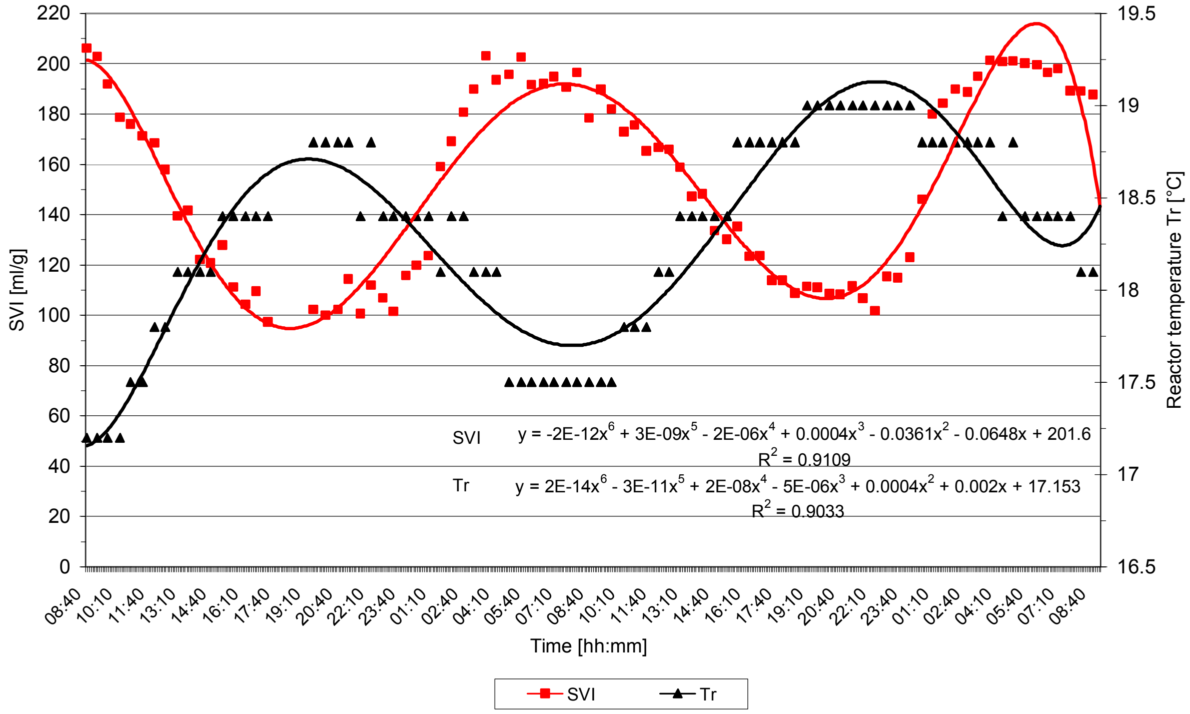


Figure 11-17 Two-day SVI and T_r profiles

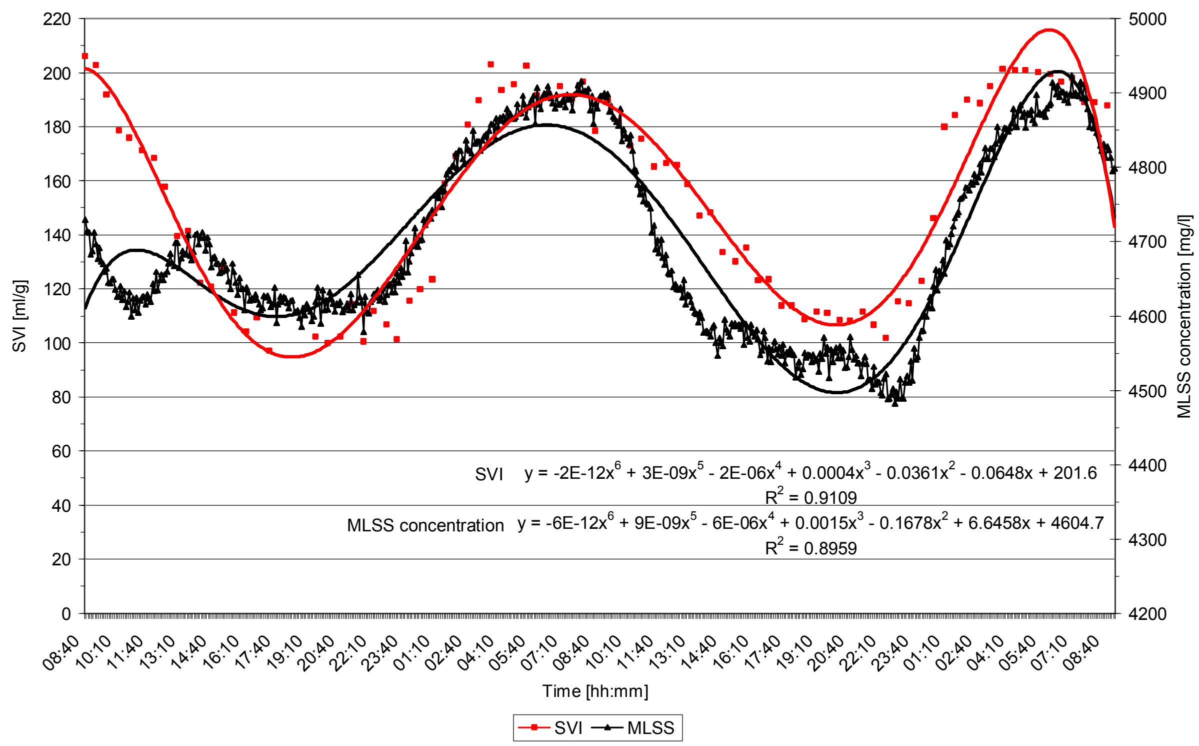
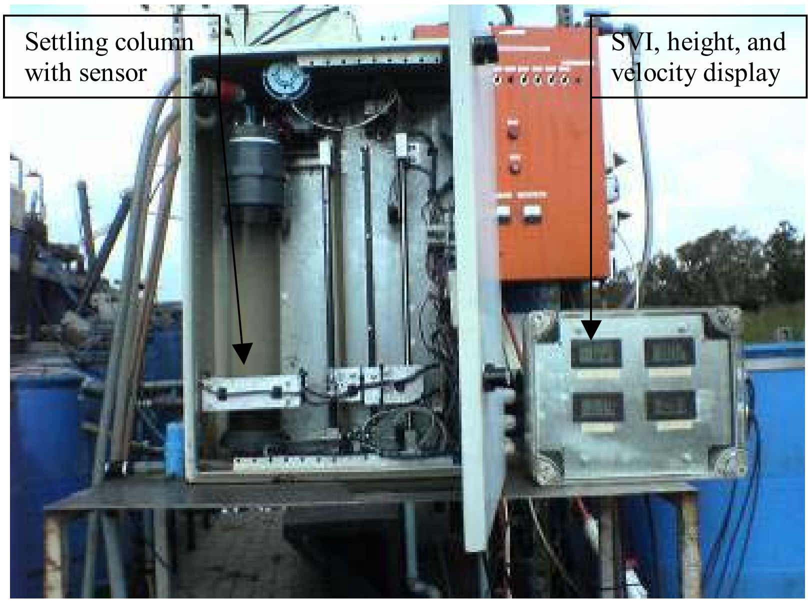


Figure 11-18 Two-day SVI and MLSS concentration profiles

11.6 Appendix F: Photograph of MLSS settling meter



Photograph 1 MLSS settling meter and output display

11.7 Appendix G: Settleability factors summary

11.7.1 Biofloc composition and structure

Table 11-7 Biofloc composition and structural properties affecting settling aspects

Parameter	Improve settling	Worsen settling	Impact description	Typical range	Reference
Density	Higher density with specific gravity (SG) of floc up to 1.06	Lower density with SG of floc up to 1.02	Heavier particles settle and compact faster	1.020	Bień *et al.*, 2005; Murthy 1998; Andreadakis, 1993;
ECP	More ECP (up to 15%) protects biofloc	Less ECP	ECP Layer decrease surface roughness, provides protective coat to flocs	N/A	Liss *et al.*, 2002; Frolund et al., 1996;
Growth stage	End of log growth phase, start endogenous	Log growth or end of endogenous	Non-settleable at start, dispersed at end	N/A	Kolmentz, 2003;
Organism type	Floc former: filament ratio balance; higher organisms: swimming or crawling, such as protozoans and rotifers	Microorganism imbalance: filaments dominate over floc formers	Filaments dominance prevent settling (leads to bulking), Bridging between flocs, Floc formers suppressed, Filaments prevent downward sludge and upward water movement Higher organisms feed on dispersed flocs and free bacteria	3-5 filaments per floc-former	Martins *et al.*, 2003; Forster and Dallas-Newton, 1980; Blackbeard *et al.*, 1986; Bux and Kasan (1994a);
Polyphosphate	Higher P increases settling velocity	N/A	Cells store polyphosphate, P increases biofloc density	N/A	De Clercq, 2003;
Porosity	Low porosity or high porosity	High porosity	Low porosity biofloc has higher density and is firm and compact and improves settling, but high porosity can also improve settling velocity of aggregate, as water can rise through settling blanket flocs Larger size more porous, and resulting lower density Low DO cause filaments and irregular shaped porous flocs	N/A	Martins *et al.*, 2003; Barbusiński and Kościelniak, 1995; Námer and Ganczarczyk, 1993;
Shape	Irregular shaped improve clarification efficiency and bridging Round, regularly shaped improves settling velocity and compression	Sphere (reduce clarification efficiency)	Shape away from sphere reduces settling velocity but improves sweep flocculation	N/A	Martins *et al.*, 2003;
Size	Medium size 200-500 µm	Too Small (no filtering effect) or too large (too porous and low density)	Balance between growth and fragmentation Settling velocity directly related to size (diameter) Anaerobic inside large flocs: break-up Surface shear increases with floc diameter	0.5 to 1000 µm	Spicer and Pratsinis, 1996; Kolmentz *et al.*, 2003 ; Randall *et al.*, 1992; Wilén, 1999;
Surface charge	Higher charge	Lower charge	Negative surface charge provides negative adsorption sites to bind to positive metal cations Surface charge influences filament length (coil or straight)	-20 to -50 mV; -15 to -30 mEq/gSS	Bux and Kasan, 1994b; Liss *et al.*, 2002; Forster, 1976; Őrmeci and Vesilind, 2000;
Surface solvent interaction (hydrophobicity)	Hydrophobicity larger (hydrophobic surface)	Hydrophobicity smaller (hydrophilic surface)	Cells and flocs adhere easier to hydrophobic surface	N/A	Liss *et al.*, 2002; Agridiotis *et al.*, 2006;

11.7.2 Wastewater characteristics

Table 11-8 Wastewater characteristics affecting settling aspects

Parameter	Improve settling	Worsen settling	Impact description	Reference
Alkalinity	Normal alkalinity	Low alkalinity	Low alkalinity – no buffer for nitrification loss – defocculation High alkalinity increases settling rate (>500 mg/ℓ as $CaCO_3$)	Nell, 1980; Rasmussen *et al.*, 1993
Ammonia	Low ammonia concentration < 1.5mg/ℓ	Higher ammonia concentration	Nitrification bacteria attached to surface of compact flocs	Kruit *et al.*, 2002; Wanner *et al.*, 1988
Bacteria	Floc formers: filaments ratio balance	Filaments > floc-formers Floc formers > filaments	Filament growth leads to bulking and settling reduction	Tandoi *et al.*, 2006;
C: N: P or nutrient composition or trace elements	COD: N: P > 100:5:1 COD: NH_4 > 5 (nitrogen limited)	COD: N: P < 100:5:1 COD: NH_4 < 5 (carbon limited) Iron concentration low	Filaments favour N and P deficiency High C synthesis of cells and ECP production, but low C fungal growth, filaments Endogenous growth phase, filaments	Tandoi *et al.*, 2006; Nakhla and Lugowski (2003); Durmaz and Sanin (2001); Nell, 1980; Ekama *et al.*, 1997; Al-Yousfi *et al.*, 2000
Floc water	Bound floc water	Capillary water	Well formed flocs holds bound floc water, Deflocculated flocs hold capillary water, Bound water is released and decreased at low DO, Bound water is decreased at high salinity and conductivity.	Sürücü and Çetin, 1989; Forster, 1976; Sanin, 2002
FOG	No excessive quantities	Fats oils grease (FOG) from industrial sources	FOG coat flocs, and interfere with bacterial activity structure FOG covers porosity channels, and hinders water flow and entrap air bubbles	Gerardi, 2002
Metal cations	Divalent (Copper > Calcium > Magnesium selectivity to floc matrix) Divalent: Monovalent ratio > 0.5	Monovalent (sodium, potassium, ammonium)	Charge bridging and when by divalent ion, a larger surface area Biofloc is an ion exchange medium: monovalent ion exchange for divalent ion (Calcium instead of Magnesium or Sodium) Lower net negative surface charge and lower interparticle distance Increase floc size and density, stable structure, decrease porosity with divalent ions Binding ability of charged and uncharged groups on ECP	Murthy, 1998; Biggs *et al.*, 2001; Gerardi, 2002; Sürücü and Çetin, 1989; Tandoi *et al.*, 2006; Urbain *et al.*, 1993; Bruus *et al.*, 1992; Novak *et al.*, 2001;
MLVSS	Low active fraction	High active fraction	Settleability decreases at higher active fraction (or young sludge age)	Catunda and Van Haandel, 1992; Gerardi, 2002
Nitrate	Nitrate low < 1 mg/ℓ	Nitrate > 1 to 2 mg/ℓ (Anoxic to aerobic zone)	Filaments reduce NO_3 to NO_2 and will proliferate Floc formers reduce NO_2 to N_2 to proliferate Anoxic conditions in secondary settling tank release insoluble nitrogen gas bubbles which attach to flocs and float to surface	Hercules *et al.*, 2002; Sötemann *et al.*, 2002
Nitrogen gas	Denitrification that is completed improves compression	Denitrification not complete	Insoluble nitrogen gas adhere to bioflocs and specifically filaments, increase biofloc buoyancy	Madoni *et al.*, 2000; de Clercq, 2003
pH	Neutral pH near 7 (range 6.5 to 8.5)	Alkaline pH (pH > 8.5) or acidic pH (pH < 6.5)	No large variations in pH for stable MLSS settling, Alkaline conditions can improve settling, Filamentous fungi growth at low pH, filament proliferation when denitrification incomplete for alkalinity recovery Negative charge reduces at lower pH Deflocculation at low pH	Nell, 1980; Sürücü and Çetin, 1989; Pitman, 1975; Ekama *et al.*, 1997; Drysdale *et al.*, 2000; Gerardi, 2002;

Septicity	Increase septicity	Decreased septicity	Lower bacterial fibril charge	Gerardi, 2002
Sewage feed age	Fresh sewage (normal age) Low levels of sulphide no impact (0.5 – 2.0 mMol)	Long sewage feed age: septic sewage Acetate and sulphide: carbon sources for filaments, Sulphide from industrial sources	Filament dominance under septic conditions Deflocculation at S > 2.7 mMol	Kjellerup *et al.*, 2001; Martinez *et al.*, 2006; van Niekerk *et al.*, 1987; Jenkins *et al.*, 1984
Soaps, detergents, emulsifying agents	No excessive quantities	High concentrations industrial sources	Surface active compounds cause deflocculation of colloids, dispersed cells, small flocs, Decrease surface tension and attack perimeter of floc, Foam production and toxicity.	Kjellerup *et al.*, 2001; Gerardi, 2002
Solids content	Normal MLSS concentration: 3000 to 6000 mg/ℓ (Extended aeration)	Low MLSS concentration High MLSS concentration	All aspects of settling related to solids content or MLSS concentration MLSS settling velocity and concentration modelled accordingly	Bhargava and Rajagopal, 1993; Catunda and Van Haandel, 1992
TDS	High TDS, specifically salinity (sodium and potassium ions) High strength: up to 0.06 M for monovalent and divalent cations	Low TDS Dilution of sample with water	High TDS: Larger floc area, elongated shape, decreased shape factor due to electrostatic and hydrophobic reactions Low TDS: Deflocculation, high turbidity Diluted sample has lower ionic strength, leads to deflocculation	Moghadam *et al.*, 2005; Gerardi, 2002; Chaignon *et al.*, 2002;
Temperature: long- term (seasonal variation)	Summer and early autumn (high temperature)	Winter and early spring (low temperature)	Filament growth at lower temperature ($T_r < 20°C$), *M. parvicella* growth only at $T_r < 20°$; Zoogloea growths more at lower T_r	Kristensen *et al.*, 1994; Mamais *et al.*, 2006; Al-Yousfi *et al.*, 2000;
Temperature: short-term (diurnal variation)	Day (high Temperature)	Night (low temperature)	Physical changes to water and biofloc	Makinia *et al.*, 2005;
Toxicants	Limited toxic concentrations	Toxic (industrial) discharges such as organic compounds e.g. phenol	Deflocculation from biofloc disintegration Large viscous clumpy bioflocs Instantaneous floc break-up	Morgan-Sagastume and Allen, 2003; Wilén, 1999; Schwartz-Mittelmann and Galil, 2000;
VFA and LCVFA	VFA and LCVFA low concentration	VFA and LCVFA concentration	Filaments use VFA to proliferate	Kruit *et al.*, 2002;
Viscosity	Low	High	Improved MLSS settling at lower viscosity Viscosity is inversely related to T_s	Hasar *et al.*, 2004;

11.7.3 Process and reactor configuration

Table 11-9 Process and reactor configuration affecting settling factors

Parameter	**Improve settling**	**Worsen settling**	**Impact description on settling aspect**	**Reference**
Aeration intensity	Low velocity surface aeration or bubble aeration	High velocity surface aeration or over - aeration causing turbulence	Physical floc break-up of shearing of sections High shear leads to irreversible floc size reductions	Ekama *et al.*, 1997; Biggs *et al.*, 2003; Parker *et al.*, 1996;
Aeration method	Fine bubble Surface aeration with draught tubes	Coarse bubble Point source surface aeration	No low DO tension in bubble aeration Turbulence for floc break-up	Van Huyssteen *et al.*, 1990; Ekama *et al.*, 1997
Aerobic reactor zone size	>55% to 60%	< 55 to 60%	Filament proliferate at low DO conditions and large anaerobic zones	Ekama *et al.*, 1997; Cooper *et al.*, 1995; Tandoi *et al.*, 2006; Pitman, 1991;
Anaerobic reactor zone size	Short anaerobic retention time Anaerobic reactor < 10%	Longer anaerobic retention time Anaerobic reactor > 10%	Deflocculation at long anaerobic time Filament growth at large anaerobic zone	Wilén, 1999; Cooper *et al.*, 1995;
Attached growth	Support material available for attached growth in reactor	No attached growth, only suspended growth in biofloc	Biofilm carrier material in reactor requires no RAS recycle Biofloc grow on inert particle or carrier such as foam or plastic discs, Maximum particle volume 40% to ensure complete mixing Reduce filamentous growth in biofilm due to anoxic zone	Wanner *et al.*, 1988; Ødegaard, 2000;
Combined sewers	Separate	Combined	Combined infiltration, high hydraulic loads due to storm water	Wilén, 1999;
Environmental	Quiescent conditions	Rainfall, wind	Rainfall dilute inflow through infiltration, hydraulic load Wind will enhance density currents and move surface scum	Ekama *et al.*, 1997; Van der Walt, 1998;
HRT in settling tank	As per design	Too short	Microorganism washout at low HRT over design capacity	Pretorius, 1987;
Inflow feed configuration	Discontinuous or intermittently fed Cyclic loading	Continuously fed	Substrate gradient favours floc-formers above filaments Larger stronger flocs with cyclic	Dangcong *et al.*, 1999; Wilén and Balmer, 1999;
Mixing intensity	Gentle mixing: for contact and suspension	Low intensity mixing: dead zones High intensity mixing: unwanted DO input	Bioflocs contact, induce flocculation Mixing reduce wall effects during settling tests in cylinders	Wilén, 1999; Grijspeerdt and Verstraete, 1997; Berktay, 1998;
Prefermentation	No prefermentation, (or Prefermentation depending on VFA)	Prefermented settled sewage reactor feed	*M. parvicella* store LCVFA under anaerobic conditions But 7.5 mg/ℓ VFA per 1 mg /ℓ P can minimise anaerobic zone size and improve settling	Mamais *et al.*, 2006; Cooper *et al.*, 1995;
Primary settling	Primary settling No primary settling	No primary settling Primary settling	Remove some RBCOD and VFA which simulates growth of filaments such as *Microthrix parvicella*	Mamais *et al.*, 2006; Tandoi *et al.*, 2006;

			Nutrient rations change	
Reactor configuration	Plug flow or SBR or oxidation ditch Declining growth phase	Completely mixed reactor Log growth phase	Spatial substrate gradient in plug flow favours floc-formers Temporal substrate gradient SBR favours floc-formers Completely mixed reactor has backmixing and mobile organisms proliferate	Droste, 1997; Janczukowicz *et al*., 2001; Azimi and Horan, 1991; van Niekerk *et al*., 1987; White, 1976; Pitman, 1975; Kruit *et al*., 2002
Reactor surface flow	Free surface flowing Reactor zone surface organism removal Mechanical foam removal	Internal recirculation of foam/scum microorganisms Trapped foam	Remove scum/foam organisms out of system Surface layers with foam / floating matter retention age > sludge age of bulk activated sludge : due to trapping and recirculation, cause foam proliferation Surface aerators have surface pump-back action to return foam upstream	Tandoi *et al*., 2006; Blackbeard *et al*., 1986; Madoni *et al*., 2000; Pitman, 1991; Pitman, 1996
Selectors	Sectionalised selector short HRT: 5 minutes in 3 sections Selectors loading: 100 mg COD. g MLSS $.h^{-1}$	HRT not suitable Too large or too small selector Selector loading too low or high	High VFA uptake by floc-formers, substrate gradient favours floc-formers Flocformers are fast-growers, filaments are slow-growers Too small selector: substrate into reactor, Too large selector: removal of substrate too large	Tandoi *et al*., 2006; Kruit *et al*., 2002; Cenens *et al*., 2000; Van Niekerk *et al*., 1987;
Settling tank design	Deep tank (>5m): sweep flocculation Large centre well: reflocculation Sloped floor: fast sludge removal Baffles: surface scum removal	Shallow tank (< 5m depth) Small centre well Flat floor: slow sludge removal No baffles	sweep flocculation reflocculation denitrification surface foam	Parker *et al*., 1996;
Settling tanks configuration	Tanks in series	Tanks in parallel	Micro-organism selection occurring in tanks by removing filaments in 1st tank	Kim *et al*., 1998;
Simultaneous precipitation	Precipitation	No precipitation	C and P nutrient deficiencies and filamentous growth from precipitation Stabilisation time required to restore settling	Ødegaard, 2000; Ericsson and Eriksson, 1988; Janssen *et al*., 2002;
Turbulence: hydraulic jump or pumping	Low turbulence and gentle transfer (Can enhance settling if DO is increased)	High turbulence, high pump impeller velocity	Biofloc deflocculate during shear, Break-up more during aggregation	Wilén, 1999;
Ultrasound	Sonification time low (about 180s) at 22kHz and 16 µm,	Sonification time high (about 360s) at 22kHz and 16 µm	Ultrasonic cavitation bubbles can destroy filaments with Increased settling velocity, lower SVI, lower hydration, but at high intensity shear cause cell destruction, dispersed floc, and irreversible deflocculation	Bień *et al*. 2005; Wünsch *et al*., 2002;

11.7.4 Operational factors

Table 11-10 Operational factors affecting settling factors

Parameter	**Improve settling**	**Worsen settling aspect**	**Impact description on settling aspect**	**Reference**
Additives: Synthetic polymers, inorganic coagulants, anti-foaming agents, weighing agents	Structure change to compact dense flocs; Hydrophobicity increase	Overdosing of these additives, and introduction of new constituents	Fast changes within 30 to 45 min., ideal as short-term standby or emergency use but temporary measure only (e.g. 4 hr) with relative high cost of chemicals Ballasting effect, floc restructuring, thin biofilm Initial lag period, SVI, ISV, SV_{30} improvement	Wilén, 1999; Agridiotis *et al.*, 2006; Patoczka *et al.*, 1998; Vanderhasselt and Verstraete, 1999; Vanderhasselt *et al.* (1999a);
Anaerobic time	Shorter anaerobic Anaerobic reactor < 10%	Longer anaerobic time	Deflocculation at long anaerobic time Filament growth at large anaerobic zone	Wilén, 1999; Cooper *et al.*, 1995;
Anoxic reactor outlet nitrite	Low NO_2concentration	High NO_2 concentration (>1 to 2 mg NO_2/ℓ)	Bulking sludge due to high nitrite concentration Control the a- recycle according to denitrification potential	Lilley *et al.*, 1997;
Bactericide	Chlorine, hydrogen peroxide, ozone Lower SVI and effluent suspended solids, higher settling velocity	Overdosing of bactericide: effluent SS increase, Floc formers can be affected Introduction of new constituents	Non-specific bulking control by filament killing Temporary solution High cost 2 to 8 mg Cl_2/(gMLSS.d) for 19 days reduces DSVI from 230 to 48 mℓ/g	Seka *et al.*, 2001; Van Leeuwen and Pretorius; 1988; Wentzel *et al.*, 1988;
DO concentration	DO = 2 mg/ℓ over 24 hr in whole aerobic reactor (ideally), or minimum 1 mg/ℓ over 24 hours in all sections of aerobic reactor	Over aeration (DO>3 mg/ℓ) Under aeration (DO <1 mg/ℓ) in zones or certain times, Oxygen limitation (DO< 0.5 mg/ℓ) Intermittent or alternating aeration	Increase DO: mechanical or point source aerators turbulence will shear sensitive flocs, Filament dominance, Deflocculation, irregular weak flocs, low ECP production; low adsorption colloids; porous flocs; anaerobic period determines deflocculation, Diffusional limitation inside flocs at a low DO, DO according to organic loading [2 mg/ℓ DO for 0.5 kg COD/kg MLVSS/d], Higher DO (>2 mg/ℓ) create large stable compact flocs, High DO and over-aeration cause foams; High DO in a-recycle to anoxic zone reduces BNR efficiency.	Jones and Franklin, 1985; Kabouris and Georgakakos, 1990; Kjellerup *et al.*, 2001; Martins *et al.*, 2003; Tandoi *et al.*, 2006; Wilén, 1999; Wilén and Balmér, 1999; Pitman, 1991;
Organic loading	Organic loading high	Organic loading low Organic loading overload (long-term)	Filament dominance at low substrate, larger surface: volume Floc formers have higher substrate utilisation rates Floc formers cannot absorb too high substrate loading: break up Diffusional resistance inside flocs for high loading: break up Size of flocs increase with increased loading	Jones and Franklin, 1985; Tandoi *et al.*, 2006; Barbusiński and Kościelniak, 1995; Pitman, 1975;
Plant stability	Start-up	Steady state	Start up unstable, microorganisms need period of a few sludge ages to acclimatise Bioflocs flocculate poorly in log growth phase when compared to declining growth phase	Kolmetz *et al.*, 2003;
RAS recycle rates	High RAS recycle (>1)	Low RAS recycle (<1)	High contact for flocculation; Prevent clarifier denitrification	Cloete and Muyima, 1997;
Sludge age (SRT)	SRT high (>15 days for EPBNR)	SRT low (< 10 to 15 days EPBNR), or very high	High sludge age (15 to 20 days): Biofloc more stable, compact, floc surface more hydrophobic, less negatively charged, less hydrated, large ECP layer gives smoother surface and protective coat; Higher life forms scavenge effluent dispersed fragments; High sludge age: Filament dominance at very high sludge age; Low sludge age: weak buoyant floc shear easily no structure;	Liss *et al.*, 2002; Liao *et al.*, 2001; Akça *et al.*, 1993; Kaewpipat and Grady, 2002; Nakhla and Lugowski, 2003; Gerardi, 2002;

11.7.5 Settleability failure identification

Table 11-11 Settleability failure identification guidelines

(adapted from Jenkins *et al.*, 1986)

Name of problem	Nature of problem / alternative names	Characterization of problem	Reasons for problem
Dispersed floc	Flocs do not aggregate, small clumps (10 to 20 µm) or single cells (Dispersed growth, straggler flocs)	Turbid effluent No or very low zone settling velocity Low sludge age from loss of sludge in settling tank	Low amount of ECP High organic loading Start-up of plant or low sludge age Toxicity event
Filamentous floc	Strong, large flocs Filaments extend from flocs into bulk solution, interfloc bridging Interfere with settling and compression Filaments cause foaming (*Norcadia* or *Microthrix parvicella*) (filamentous bulking)	Clear effluent Poor thickening and low RAS concentration Increased sludge blanket High SVI and high SV_{30}	Nutrient deficiency High organic loading / shock load Low DO concentration Low pH Septicity or high sulphide levels
Floating flocs	Bio surfactants or surface active agents, from foam forming filaments Floating foams from hydrophobic filaments, accumulate on surfaces Bacteria causing foams dominate	Foams visible in aerator and settling tank, aesthetic Carryover cause high nutrient content in effluent Low density billowy foam or heavy dense foam	Internal circulation of material and not removed from system Low temperature or seasonal changes Low sludge age Low DO concentration High organic shock load Industrial surface active agents
Non-filamentous floc	Sludge flocs become more hydrated and reduce density Bound water in sludge flocs due to hydrophilic biopolymers Exocellular slime or jelly-like characteristics of sludge solids (viscous bulking, hydrous zoogloeal bulking, non-filamentous bulking)	Low settling velocity Low compression and low RAS concentration Increased sludge blanket High SVI	Low sludge age Nutrient deficiency High organic loading / shock load Low DO concentration
Pin floc	Compact dense flocs settle rapidly, leaving lighter flocs in suspension Weak, small flocs Break up of large flocs (Pin-point floc, unsettleable floc)	Cloudy turbid effluent with fine particles High zone settling velocity Few filaments Low SVI	High DO concentration High turbulence from aerators or hydraulic jumps High shear High sludge age Low organic loading Absence of filaments
Rising flocs	Gas entrainment or gas release gives buoyancy to flocs Bubble aeration MLSS supersaturated with air Denitrification of nitrate in blanket with insoluble nitrogen gas release Long retention in settling tank make sludge anaerobic with gas release	Settle rapidly and compact well Flocs or clumps of flocs rise rapidly to surface, within 30 minutes to interfere with SVI test	Low RAS flow rate High sludge blanket or tank floor accumulation Reactor denitrification incomplete

11.7.6 Settleability impacts due to filamentous micro-organism dominance

Table 11-12 *Microthrix parvicella* dominance and settling effects in a NDBEPR process (adapted from Tandoi *et al.*, 2006)

Parameter	***Microthrix parvicella* compared to floc-formers**	***Microthrix parvicella* dominance impact on settling**
Biocides	20 to 200 $kgCl_2/kgSS$ effective for *Microthrix parvicella*; 2 kg Cl_2/kg SS normal dosing for other filaments	Hydrophobic cell wall prevents penetration to reduce *Microthrix parvicella* dominance
Cell wall	*Microthrix parvicella* hydrophobic	Supports formation of stable foams, Scum and bulking in same reactor attributed to *Microthrix parvicella*
Electron acceptors	*Microthrix parvicella* uses DO, NO_3, NO_2	All reactor zone grower (anaerobic, anoxic, aerobic) and related settleability deterioration
Maintenance energy	*Microthrix parvicella* has lower requirements, and can adapt and withstand environmental stress	Advantage under starvation conditions (low substrate loading such as C, N, O) leads to proliferation and related settleability deterioration
Oxygen affinity	*Microthrix parvicella* has high affinity	Advantage during micro-aerobic conditions During low DO concentration or plant overload More prevalent in surface aeration with low DO concentration sections
pH	Stimulated *Microthrix parvicella* growth alkaline pH (>8)	NDBEPR recovers alkalinity for resulting higher pH, and related settleability deterioration
Slowly biodegradable substrate	*Microthrix parvicella* grows well with SBCOD, and also a specialised lipid consumer	Kinetic selectors are not effective to reduce *Microthrix parvicella* dominance
Sludge age	Enhanced *Microthrix parvicella* growth at long sludge ages (>10 days)	NDBEPR process sludge age above 15 days, and related settleability deterioration
Strains	Numerous	Contradictory information; Difficult to isolate and cultivate
Symptoms	Varied indications makes identification difficult	Bulking and scum formation in same reactor
Temperature	Enhanced *Microthrix parvicella* growth at 12- 15°C (winter temperatures) *Microthrix parvicella* growth stops above 20°C (summer temperatures)	Seasonal / periodic dominance, and related long-term changes in settleability
Volatile fatty acids	Enhanced *Microthrix parvicella* growth with LCVFA in anaerobic reactor zones	LCVFA enriched settled sewage feed from prefermenters; *Microthrix parvicella* proliferation from anaerobic reactor in NDBEPR process and related settleability deterioration

Appendix H: Summary of regression model variable results

Table 11-13 Regression variable results

Parameter	Residual sum of squares (absolute)	Standard error of estimate	Proportion of variance explained [%]	variable	Value	Standard error	t-ratio	p value	95% confidence interval		
									95% (+/-)	Lower limit	Upper limit
SVI	33051.9430	20.0767	71.0372	a	872.4200	159.1041	5.48	0	316.5058	555.9142	1188.9258
				b	-4624176.0614	445895.8905	-10.37	0	887020.6949	-5511196.7563	-3737155.3665
				c	4823.4020	1611.5791	2.99	0.0037	3205.9143	1617.4878	8029.3163
t_umax	2419.6831	5.4322	70.2409	a	239.5624	43.0489	5.56	0	85.6372	153.9252	325.1996
				b	-1290679.9382	120646.3577	-10.70	0	240001.7994	-1530681.7375	-1050678.1388
				c	939.9347	436.0461	2.16	0.034	867.4264	72.5082	1807.3611
u_max	7.7978	0.3084	58.9421	a	-9.30	2.44	-3.81	0.0003	4.86	-14.16	-4.44
				b	57454.30	6848.89	8.39	0	13624.50	43829.76	71078.76
				c	-39.8603	24.75	-1.61	0.11	49.24	-89.10	9.38
u_ave	0.3879	0.0688	75.5813	a	-2.89	0.55	-5.31	0	1.08	-3.98	-1.81
				b	18433.81	1527.63	12.07	0	3038.92	15394.90	21472.74
				c	-15.18	5.52	-2.74	0.007	10.98	-26.16	-4.20
h	94532.14	33.9535	76.0927	a	1793.96	269.07	6.67	0	535.27	1258.69	2329.23
				b	-9200670.30	754092.67	-12.20	0	1500116.54	-10700786.85	-7700553.76
				c	7744.02	2725.48	2.84	0.006	5421.80	2322.23	13165.82
u1	2.4349	0.1723	32.0137	a	-1.1851	1.3656	-0.86	0.388	2.7166	-3.9018	1.5315
				b	14418.7348	3827.1866	3.77	0.0003	7613.4223	6805.31	22032.1571
				c	-31.9946	13.8324	-2.31	0.023	27.5168	-59.5115	-4.4778
u2	4.2432	0.2275	59.0884	a	-2.6708	1.8027	-1.4815	0.1423	3.5861	-6.2570	0.9153
				b	33145.3653	5052.1882	6.5606	0	10050.3181	23095.0472	43195.6834
				c	-74.7660	18.2598	-4.0946	0.0001	36.3244	-111.0903	-38.4416
u3	1.4572	0.1333	62.3507	a	-3.6732	1.0564	-3.4770	0.00081	2.1016	-5.7748	-1.5717
				b	25152.0675	2960.7089	8.4953	0	5889.7381	19262.3293	1041.8057
				c	-26.7192	10.7007	-2.4969	0.0145	21.2870	-48.0062	-5.4322
u4	0.6809	0.0911	59.5538	a	-4.1828	0.7222	-5.7921	0	1.4366	-5.6194	-2.7462
				b	19564.9547	2023.8724	9.6671	0	4026.09	15538.8655	23591.0440
				c	3.4218	7.3148	0.4678	0.6411	14.5513	-11.1295	17.9731
u5	0.5620	0.0838	33.6828	a	-3.3897	0.6561	-5.1666	0	1.3051	-4.6948	-2.0846
				b	11822.7573	1838.6975	6.4300	0	3657.7208	8165.0364	15480.4781
				c	18.7500	6.6455	2.8215	0.006	13.2199	5.5301	31.9700
u6	0.3475	0.0651	29.5519	a	-2.6835	0.5159	-5.2019	0	1.0262	-3.7097	-1.6573
				b	8411.5793	1445.7612	5.8181	0	2876.0528	5535.5265	11287.6321
				C	18.8984	5.2253	3.6167	0.00051	10.3948	8.5037	29.2932