

SECTION 5

DENSADEG PILOT TESTING - RESULTS AND DISCUSSIONS

Performance results specific to the Densadeg pilot unit is presented in this section. In Phase I, the BAF pilot units were fed effluent from the PLWTP existing CEPT process. During Phase II, the system was reconfigured so that the BAF pilot units were fed effluent from the pilot Densadeg advanced primary treatment process. In addition, the Densadeg advanced primary treatment process was tested in Phase II. Screened plant influent was pumped to the pilot test plant. In the beginning of Phase II, the Densadeg was fed this screened influent directly. However, it was realized that some form of grit removal upstream of the Densadeg was desirable to simulate full-scale conditions. A cyclone grit removal device (Teacup by Eutek) was installed in early October. This system went on-line on October 13, 2004. Most of the Densadeg data reflects the post-grit system condition.

Densadeg Data Evaluation

The pilot testing of the Densadeg was intermittent due to false starts and mechanical problems that were encountered. Sample collection continued in some cases even through the problematic periods. Figure 5.1 shows the Densadeg influent and effluent TSS concentration, and target maximum effluent TSS limit (65 mg/L). The data collected during the operational problems are highlighted in the figure. The reasons for the operational problem are given in the table footnote. For the performance evaluation presented herein the data corresponding to the process upsets (i.e., the yellow boxes shown in Figure 5.1) were excluded. In other words, only the data points corresponding to the period when Densadeg unit was running smoothly were taken into consideration.

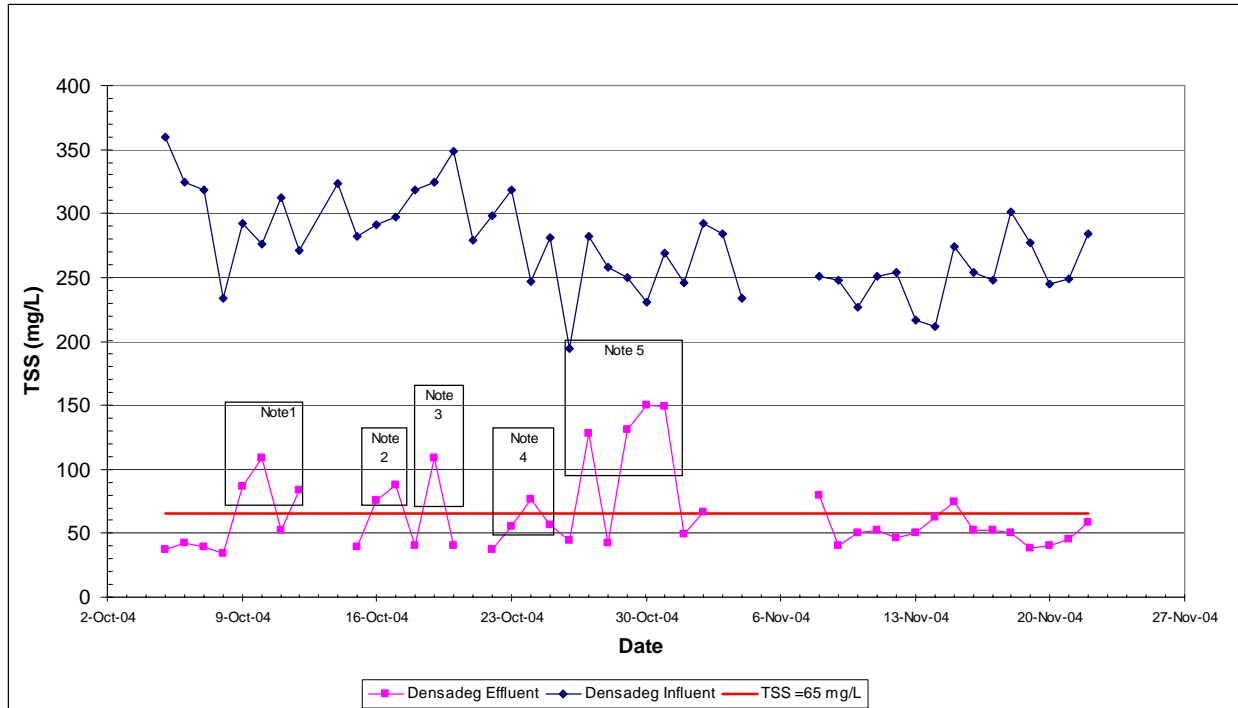


Figure 5.1. Densadeg Unit Influent and Effluent TSS Concentrations

- Notes:
1. Trash accumulation in the mixing chamber effected coagulation process.
 2. Air entrainment in flash mixing resulted in vortex formation. As a result, coagulation process was affected. Also, no chemicals were added for about 5 hours due to power failure.
 3. High value was measured due to sampler error.
 4. Densadeg unit was fed with 1 mg/L polymer due to low amount of polymer available onsite.
 5. Densadeg lost its treatment due to operational problems.

Comparison of Densadeg Performance with the Existing CEPT Performance

The Densadeg operational data during October 5 through November 22, 2004, is compared to the performance of the existing CEPT at PLWTP. Densadeg influent and effluent were sampled and analyzed for TBOD₅, SBOD₅, CBOD₅, SCBOD₅, COD, TSS, VSS, ammonia, alkalinity, TKN, and ortho-P. Comparative data for TBOD₅, SBOD₅, COD, TSS, ammonia, and alkalinity were obtained for the existing CEPT at the PLWTP for the same periods when the Densadeg unit was operating to compare the Densadeg performance with the existing CEPT.

In order to compare the performance of the Densadeg and the CEPT systems, data were examined in the form of log normal percentile plots. Data for TSS, TBOD₅, SBOD₅, and COD are presented in Figure 5.2 to 5.5. In general, the CEPT system was superior to the Densadeg system for TSS removal but not for SBOD₅ and COD removals. CEPT and the Densadeg pilot unit demonstrated similar TBOD₅ removals.

Average CEPT removal efficiencies were 86, 59, 7, and 60 percent for TSS, TBOD₅, SBOD₅, and COD, respectively. The Densadeg pilot unit removal efficiencies were 81, 64, 6, and 68 percent on average during its operation. The smaller slopes of the plots for the CEPT system demonstrate that it was more stable than the Densadeg system.

The solids content of CEPT and the Densadeg pilot unit sludges percent solids content is given in Figure 5-6. The Densadeg unit produced much thicker sludge than CEPT. The Densadeg sludge solids content ranged from 2 to 11 percent; and the solids content of the CEPT sludge varied in the range from 3.3 to 6 percent. Average CEPT and the Densadeg sludge solid content was 4 and 7.4 percent, respectively. The Densadeg unit produced sludges with higher than 6 percent solids concentration, eliminating the need for additional thickeners to achieve the desired TS concentration of 5.6 percent.

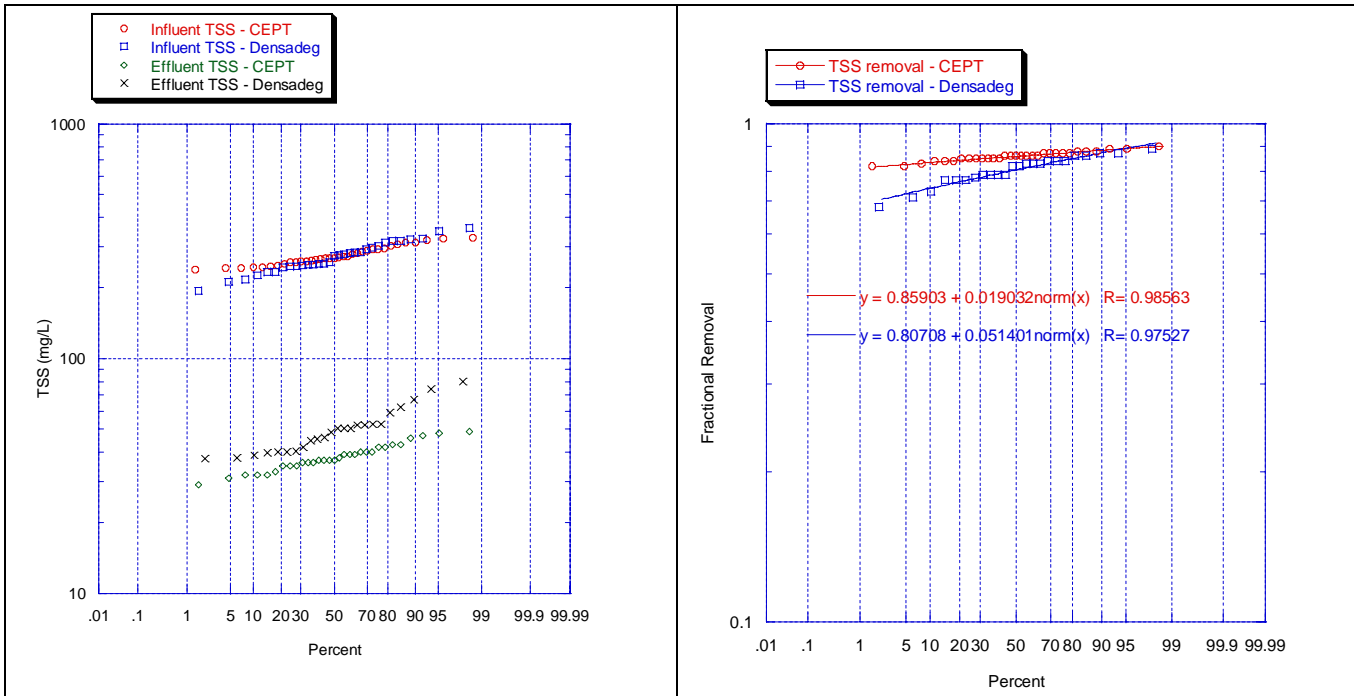


Figure 5.2. CEPT Full-Scale and Densadeg Pilot Unit Influent and Effluent TSS Concentrations and TSS Removal Efficiencies

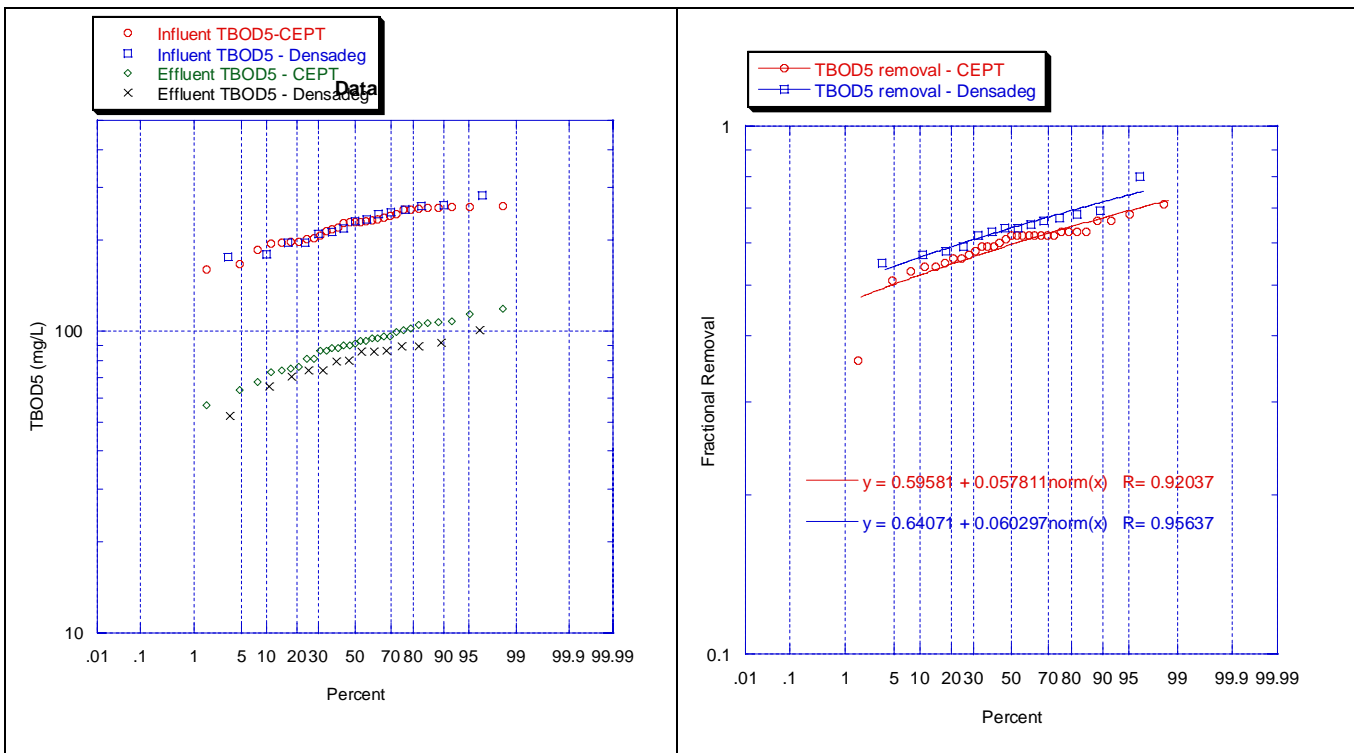


Figure 5.3. CEPT Full-Scale and Densadeg Pilot Unit Influent and Effluent TBOD₅ Concentrations and TBOD₅ Removal Efficiencies

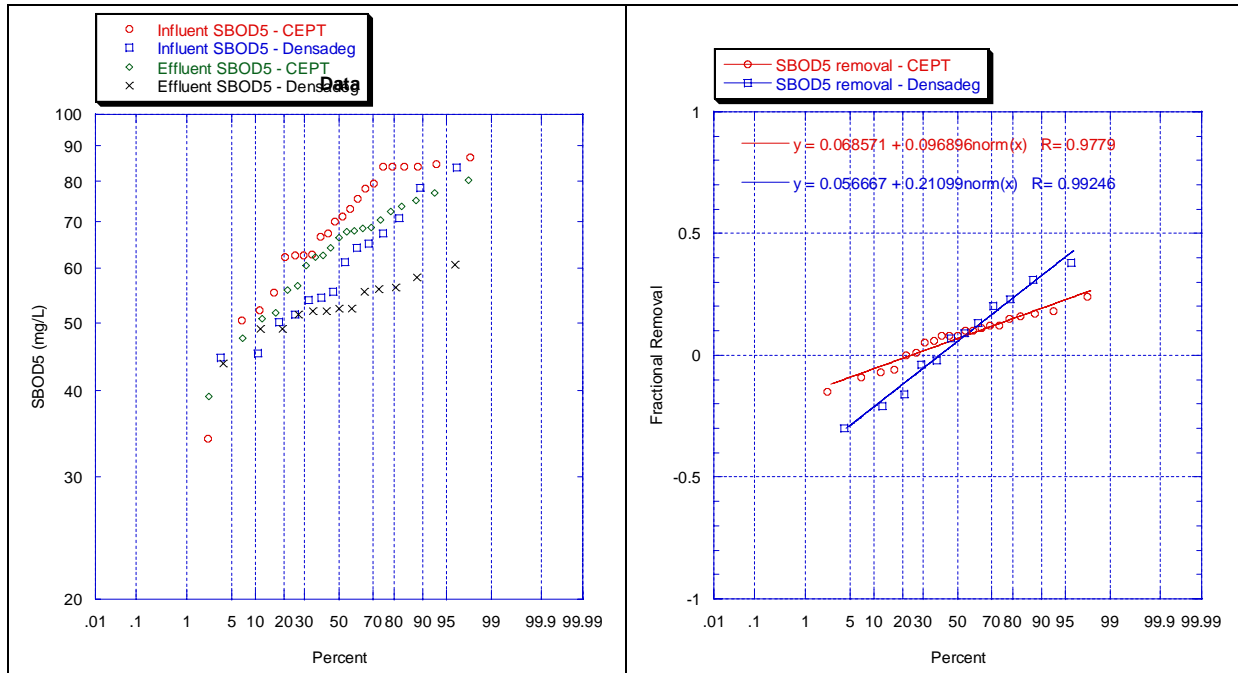


Figure 5.4. CEPT Full-Scale and Densadeg Pilot Unit Influent and Effluent SBOD₅ Concentrations and SBOD₅ Removal Efficiencies

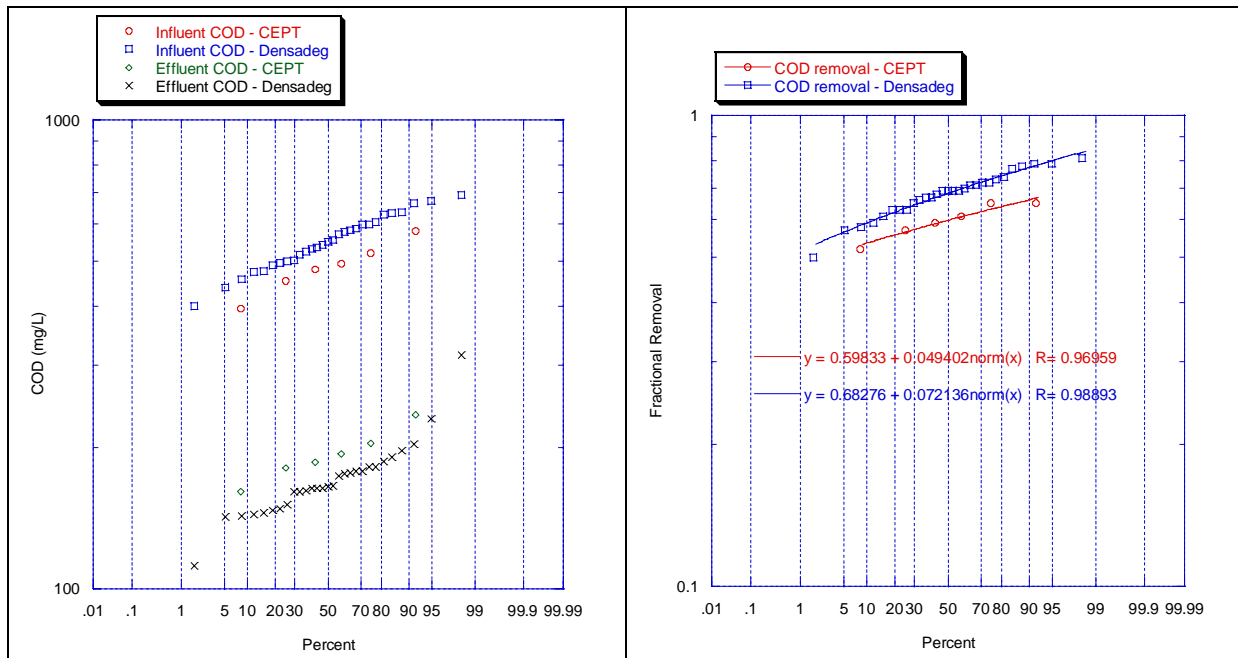


Figure 5.5. CEPT Full-Scale and Densadeg Pilot Unit Influent and Effluent COD Concentrations and COD Removal Efficiencies

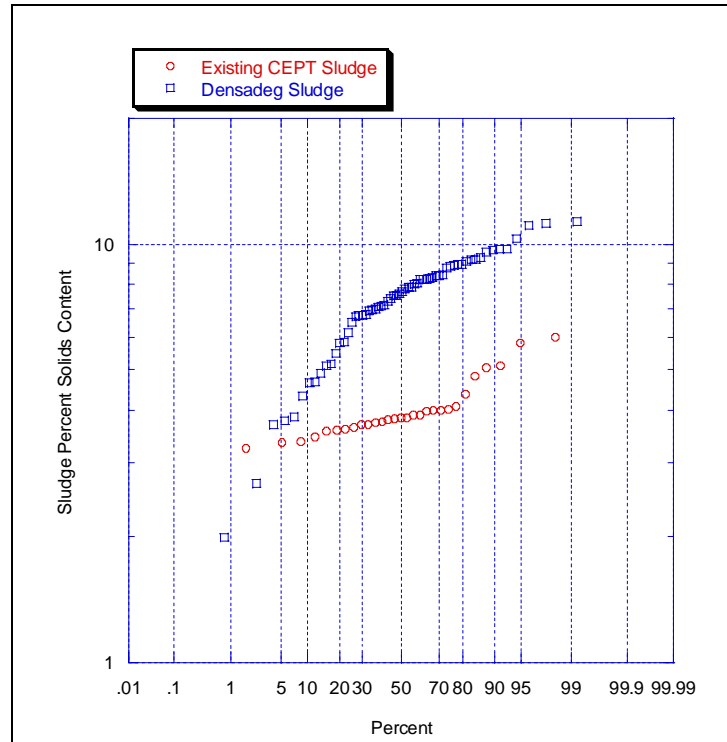


Figure 5.6. CEPT Full-Scale and Densadeg Pilot Unit Sludge Percent Total Solids Content

Effect of Installation of Grit Removal System on Densadeg Performance

A grit removal system was installed on October 13, 2004. Densadeg performance was monitored 20 days without, and 37 days with the grit removal system. However, after the first 10 days of operation (September 2 to September 12, 2004), the Densadeg unit was shut down due to operational problems, cleaned and restarted on October 5, 2004. The unit was operated 10 more days without the grit system. In order to see how installation of a grit removal system affected the Densadeg performance, data before (starting from October 5, 2004) and after the installation of grit removal system was compared. Statistical comparison was inconclusive due to the changing operational conditions. However, it appears that with the installation of the grit removal system, the average TSS loading to the Densadeg unit decreased by 20 percent from 41 lb/ft²-d to 33 lb/ft²-d on average.

Effect of Hydraulic Loading Rate on Densadeg Performance

The Densadeg unit was operated at two hydraulic loading rates. It was continuously operated at a HLR of 10.25 gpm/ft² for about two months. A rise rate of 10.25 gpm/ft² corresponds to maximum month flow of 264 mgd with 12 full-scale Densadeg units in operation. The Densadeg unit was also operated continuously at a HLR of 12.4 gpm/ft² for 24-hours, a rate corresponding to

the peak hour wet weather flow of 432 mgd with 16 full-scale Densadeg units operating. Both the operational conditions tested were based on IDI's proposal. This section presents the Densadeg unit performance at the two target HLRs.

Densadeg Performance at HLR of 10.25 gpm/ft². Average flow, hydraulic and TSS loading rate to the Densadeg pilot unit, and influent and effluent wastewater quality is summarized in Table 5.1. Densadeg data from October 5 to November 22, 2004, were considered in the performance evaluation. Removal efficiencies given in Table 5.1 are based on the 50 and 90 percentile influent and effluent values.

Table 5.1. Densadeg Average HLR, TSS Loading Rate, Influent and Effluent Wastewater Quality

Parameter	Unit	Densadeg Influent Percentile Values		Densadeg Effluent Percentile Values		Removal Efficiency (%) Percentile Values	
		50%	90%	50%	90%	50%	90%
		Flow	gpm	107.2	109.3		
HLR	gpm/ft ²	10.10	10.35				
TSS Loading	lb/ft ² -d	33.3	40.0				
TBOD ₅	mg/L	227	267	80	96	64	72
SBOD ₅	mg/L	58	76	51	60	5	45
CBOD ₅	mg/L	159	190	73	87	54	64
SCBOD ₅	mg/L	57	76	48	58	12	33
COD ₅	mg/L	553	645	172	210	68	78
TSS	mg/L	272	325	49	61	81	88
VSS	mg/L	221	260	35	46	84	89
Ortho-P	mg/L	1.126	1.600	0.04	0.053	95	99
Ammonia	mg/L	26	29	26.5	29.5	1	8
TKN	mg/L	42	46	34	38	20	29
Alkalinity	mg/L	266	283	231	247	13	18

The Densadeg pilot unit was operated at an average HLR of 10.10 gpm/ft², which is 98.5 percent of the maximum monthly flow (MMF) condition of 10.25 gpm/ft². At this HLR, the average TSS, TBOD₅ and CBOD₅ removal efficiency achieved by the unit Densadeg was 82, 64, and 54 percent, respectively. Ortho phosphorus removal in the Densadeg unit was about 95 percent.

A grab sample of the Densadeg sludge was collected two times a day and analyzed for TS and VS content. Densadeg produced a thick sludge. Average sludge percent solids content was 7.4 percent and ranged from 2 to 11 percent. Densadeg average VS content was 74 percent of TS and ranged from 62 to 77 percent of TS.

The results indicated that Densadeg unit can be used for primary treatment, phosphorus removal, and thickening. However, it required 10 times more polymer and 30% more ferric chloride to achieve nearly the same effluent quality as the existing PLWTP CEPT.

Densadeg Performance at HLR of 12.4 gpm/ft². The stress test started at time zero by ramping up the flow from 10.25 gpm/ft² to 12.4 gpm/ft² over a two-hour period to simulate PWWF conditions. The unit then continued to run at the target rise rate of 12.4 gpm/ft² for 24-hours. After evaluating the data, the Densadeg actually operated at a hydraulic loading rate of 12.23 gpm/ft² for 24 hours. This rise rate corresponds to 98.6 percent of the full-scale PWWF, or 426 mgd.

The Densadeg influent and effluent were sampled hourly during 24-hour operation. Table 5.2 shows 2-hour composite Densadeg influent and effluent TSS, TBOD₅ and CBOD₅ values at a HLR of 12.23 gpm/ft².

Table 5.2. Densadeg Influent and Effluent TSS, TBOD₅, CBOD₅ Values

Time	TSS (mg/L)			TBOD (mg/L)			CBOD (mg/L)		
	Densadeg Influent	Densadeg Effluent	Removal (%)	Densadeg Influent	Densadeg Effluent	Removal (%)	Densadeg Influent	Densadeg Effluent	Removal (%)
8:00		48.8			78.8			65.4	
10:00	257	58	77	234	92.4	61	143	75.1	47
12:00	332	39.6	88	242	74.8	69	178	57.9	67
14:00	468	56.4	88	244	88.2	64	199	70.1	65
16:00	338	45.4	87	261	95.7	63	196	78.6	60
18:00	310	48.8	84	240	94.6	61	157	79.5	49
20:00	283	49.6	82	224	91.2	59	178	83.5	53
22:00	257	43.4	83	221	96.3	56	175	85	51
0:00	310	50.2	84	257	116	55	196	113	42
2:00	294	45	85	239	90.3	62	165	80.9	51
4:00	229	36.8	84	212	82.6	61	137	72.7	47
6:00	218	39.3	82	182	64.8	64	131	56	57
Average	300	47	84	232	90	61	169	77	54

Average TSS, TBOD₅ and CBOD₅ removal efficiencies were 84, 61 and 54 percent, respectively. This corresponds to average Densadeg effluent TSS, TBOD₅ and CBOD₅ concentrations of 47, 90 and 77 mg/L. The Densadeg effluent TSS level concentration was less than below 65 mg/L, which was used as the measure of treatment failure.

Effect of Solids Loading Rate on Densadeg Performance

The daily influent and effluent Densadeg TSS and flow data from October 5 to November 22, 2004, were evaluated; corresponding solids loading rates and TSS removal efficiencies were calculated. Figure 5.7 plots effluent TSS concentration and TSS removal efficiency against solids loading rate. The average TSS loading rate applied to the Densadeg unit was 33 lb/ft²-d; the resulting average effluent TSS concentration was 49 mg/L. Increased solids loading does not appear to cause an increase in effluent TSS concentration. The Densadeg unit was able to process a solids loading rate as high as 44 lb/ft²-d.

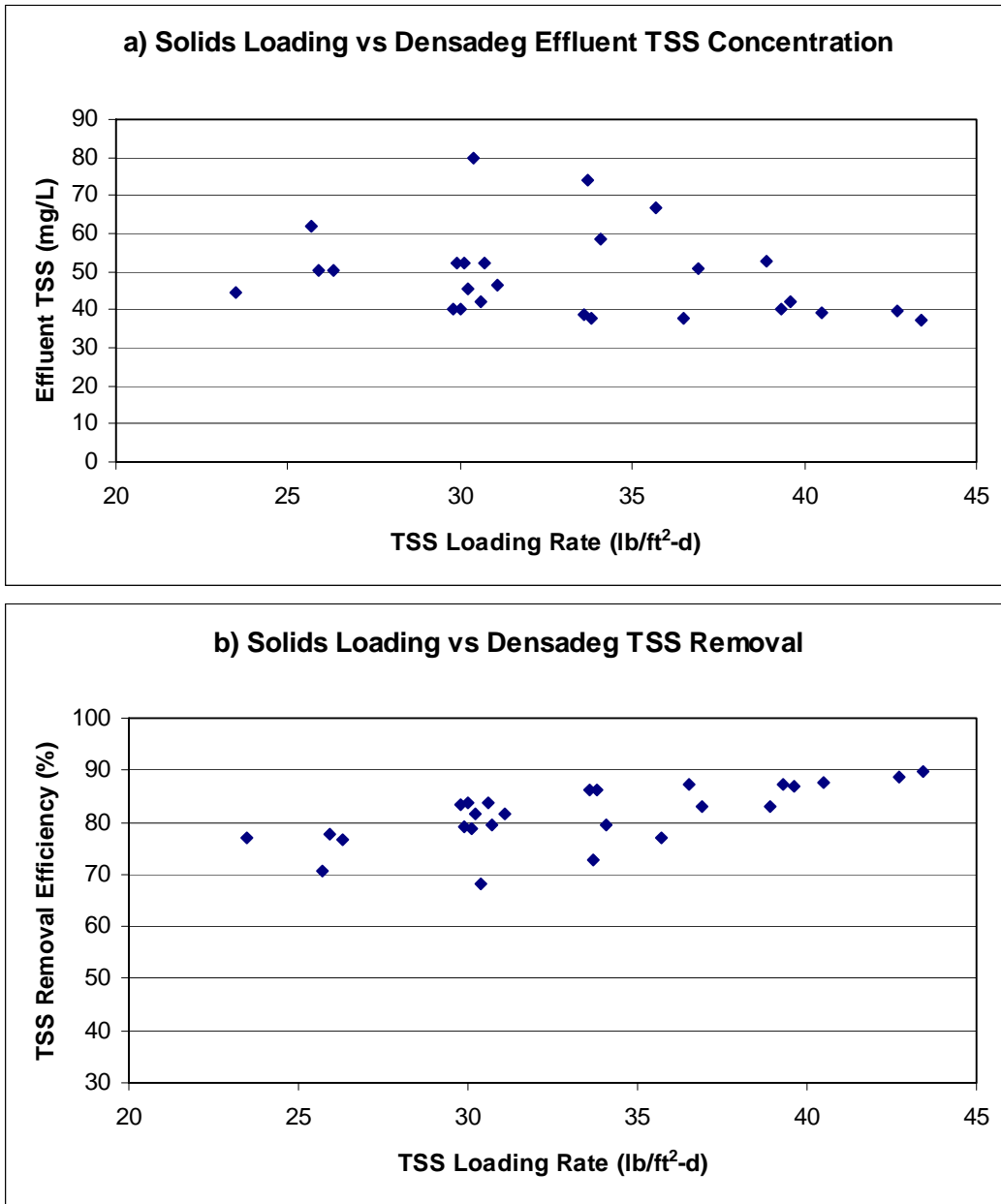


Figure 5.7. Effect of Solids Loading Rate on Effluent TSS Concentration (a), and TSS Removal Efficiency (b)

Effect of Co-settling on Densadeg Performance

One of the two BAF backwash management options is to send untreated backwash water to primary sedimentation unit for co-settling with the raw influent wastewater. The successful practice of co-settling of BAF backwash solids with primary solids has been reported for certain plants. However, none of these examples were large-scale plants in warm climate locations similar to San Diego. Therefore, limited co-settling experiments were carried out using the Densadeg to determine if the practice would cause a clarifier upset. Clarifier upsets can occur when anaerobic conditions prevail in the sludge blanket. Experience has shown that mixing biological and primary solids can lead to rapid oxygen depletion and result in uncontrolled anaerobic reactions. This is especially true for warm climates where the relatively high wastewater temperatures would speed up the process of oxygen depletion dramatically. Primary clarifier process upsets can then occur. Extreme upsets can occur when biogas formation causes the sludge particles to become buoyant and rise to the surface where they are then carried over the weir and into the effluent. Minor upsets may be less pronounced but manifest as poor primary effluent quality and a decline in sludge solids content.

Feasibility of co-settling was investigated using the Densadeg pilot unit as the primary treatment process. The Densadeg pilot unit is designed for flows up to 100 gpm, whereas, the Biostyr and Biofor C pilot units design flows are 7 and 6 gpm on average. Due to different scale pilot units, continuous operation was not possible for simulating the co-settling conditions. However, it was decided to perform a number of co-settling tests to see if the addition of backwash water stream to the raw influent would upset the Densadeg performance.

Backwash water from each BAF units was combined in the backwash tank to be used in co-settling experiments. After sampling for characterization, combined backwash water was sent to the Densadeg inlet feed line. Backwash water and raw wastewater was mixed at a ratio designed to simulate the full scale conditions. The mixing ratio of backwash water to raw wastewater was calculated as 10 percent based on Phase I pilot study findings. There was sufficient backwash water for the co-settling period to last about four hours. Densadeg effluent was sampled hourly to observe the effect of co-settling on the effluent quality. The samples were tested for TBOD₅, CBOD₅, and TSS. Appendix L gives the data for the co-settling tests.

According to the two co-settling tests performed, it appears that co-settling of backwash water did not cause an upset in Densadeg unit operation in terms of TSS, TBOD₅ and CBOD₅. The effluent quality was in the range of normal operation values. In addition to effluent characteristics, sludge density was also monitored during the co-settling experiments. The data showed no decline in sludge solids content, however, the short duration of the testing may have accounted for that. Note that this result cannot be interpreted as confirming the practice of co-settling the BAF backwash as a viable option for PLWTP. The only conclusion that can be drawn is that limited recycling of backwash to the Densadeg did not appear to produce upsets. The experiment did not reflect full-scale recycling because there was not enough backwash water produced by the BAF units for a representative experiment. Had the limited backwash experiment shown an upset, then it could have been inferred that upsets would be likely occur in a full-scale system.

Operational Requirements

Densadeg unit required addition of ferric chloride and polymer to enhance the settling characteristics of the raw wastewater.

Ferric Chloride. Target ferric addition at the Densadeg unit was 40 mg per liter of wastewater both at HLR of 10.25 and 12.4 gpm/ft². Actual ferric consumption was monitored daily. According to readings, actual ferric consumption at Densadeg was about 42 mg/L.

Polymer. IDI performed a series of Jar test with different types of polymers at different doses on the raw Point Loma wastewater. Based on the Jar test results, an anionic high density polymer called Nalco Optimer 9877 was selected to be used at Densadeg pilot unit. Polymer was purchased in 50-lb bags. An emulsion was prepared at a certain concentration, and stored in a small tank at the pilot area. Continuous mixing was provided to the polymer tank. Polymer was pumped to the Densadeg unit with peristaltic dosing pump to achieve 1.35 mg polymer per liter of wastewater treated at HLR of 10.25 gpm/ft². According to daily readings, actual polymer consumption was about 1.3 mg/L. IDI reported that polymer usage at HLR of 12.4 gpm/ft² was 1.5 mg/L. Based on the hourly readings, it was verified that average polymer concentration was less than or equal to 1.5 mg/L.

Sludge Blanket Level. A constant sludge blanket level needs to be maintained for steady state Densadeg performance. The target sludge blanket level was 3 to 4 feet for the Densadeg pilot unit. Sludge wasting rate needs to be adjusted depending on the incoming wastewater quality to achieve the target sludge blanket level.

Solids Wasting Rate. Sludge wasting rate was adjusted manually to achieve the target sludge blanket level at the Densadeg pilot unit. Sometimes sludge blanket level dropped to as low as 1 foot due to operational problems. In these instances, sludge wastage was minimized to build up enough sludge level in Densadeg unit.

Time between sludge blowdown events ranged in between 0.2 to 10 hours. It was 0.6 hours on average. Sludge wastage lasted 34 seconds on average, although it varied in between 5 to 60 seconds.

Densadeg Process Control Issues

The Densadeg system appeared to be more sensitive to diurnal and seasonal (wet weather) changes in wastewater characteristics than the existing CEPT process. This led to frequent process upsets as shown in Figure 5.1. Some of these would, perhaps, have been mitigated if the pilot unit were equipped with automated process controls. In a full-scale application of the Densadeg at PLWTP, the pilot test experience suggests it is critical to include an automated chemical feed system. Such an automated system should be flow-paced and perhaps solids mass-flow paced using online measurement of suspended solids content.

In addition to the issue of chemical dosing, the Densadeg process requires constant adjustments to control the sludge blanket depth and density. This is done through sludge wasting and through setting of an adjustable sludge draw-off device. In the pilot system, the sludge wasting was automated but the draw-off device elevation adjustment was set manually. In addition, the process

principle relies on recycling sludge from the settling tank back into the flocculation reactor. It turned out that this orchestration of sludge blanket and thickness, wasting, and recycling is not easily done manually and getting it right is important to the solids removal efficiencies that are achievable with the Densadeg. More importantly, failure to properly orchestrate these adjustments lead to process upsets. IDI indicated that full-scale systems include sonic sludge blanket level sensors used to control sludge blanket level. It is not clear how the entire balance of process components described above would be automated to reduce the need for constant operator attention. Under the best circumstances, a highly skilled instrumentation and controls team would be needed to maintain the control components.

SECTION 6

COST IMPLICATIONS OF STUDY RESULTS

In June 2003, BC submitted a draft report assessing the feasibility and requirements of upgrading the PLWTP with BAF secondary treatment. This report included the preliminary design proposals that were generated by the manufacturers. The design was based on the vendor's standard performance assumptions. Site-specific pilot trials on the PLWTP wastewater had not been performed at the time of the vendor's proposals. Budget level cost estimates were prepared and presented in that report pending verification of process performance through pilot testing. In this section, the understanding of BAF facility and O&M requirements is revisited considering the results of the pilot study. Regardless of the pilot study results, recent escalation of material costs—primarily the costs of steel, fuel, and concrete—will likely increase the capital cost required for the proposed BAF and solids handling facilities above what was estimated previously in 2003. Brown and Caldwell therefore recommends new cost estimates to be calculated as part of a preliminary design effort should the City go forward with plans to provide full secondary treatment at PLWTP.

Facility Components and Sizing

BAF Process. The design criteria used by the manufacturers in sizing BAF proposed full-scale facilities and estimating solids handling requirements are presented in Section 3. During the pilot study, maximum month and peak loading conditions were simulated and the performance of two pilot-scale BAF units tested. The results of this testing are described in Section 4. In general, each of the BAF pilot unit met performance requirements under simulated hydraulic and organic loading conditions mentioned above. Therefore, design loading assumptions that formed the basis of facility sizing in the original full-scale proposals were verified. Moreover, the results indicate that the proposed media column height for Biostyr could even be reduced without compromising the ability to meet regulatory limits, even at peak hydraulic loading conditions. Although the pilot test validated the assumptions leading to the earlier cost estimates, recent escalation of material costs will likely increase the capital cost required for the proposed BAF facilities above that which was previously estimated.

Solids Handling. Solids yields were tested during the pilot study. Phase I results confirmed assumptions used to estimate biological solids production in the earlier feasibility study. In Phase II, however, the estimated solids yield was higher than expected, particularly for the Biostyr process. In both cases the yields were higher than values expected for conventional activated sludge systems. Although the reason for the higher yield are currently not known, it is prudent to plan and develop budget level cost estimates based on the pilot study results to avoid the potential shortfall in land and funding should the actual yield be accurately depicted by the level derived from the pilot study. During predesign, agencies operating full-scale facilities could be contacted for data to determine if similar yield rates are observed. The cost estimates could then be refined at that stage.

Densadeg. The results of the Densadeg pilot testing confirmed that the design hydraulic loadings used in the earlier design proposal by IDI were valid for the Densadeg. However, it was learned that the complexity and sensitivity of the Densadeg to fluctuations in wastewater quality may not be suitable for full-scale application at PLWTP given the relatively simplicity and effectiveness of the existing CEPT process. Should the City be inclined to replace CEPT with Densadeg in the future as a space saving measure, the capital costs estimated in the earlier proposal and feasibility report for the Densadeg appear to be valid based on the pilot test results.

Operations and Maintenance Costs

BAF Process. The largest contributing O&M costs for the BAF process are:

- The power consumption for process aeration
- Backwash management costs

During the pilot testing, the process aeration requirements for each of the pilot units were evaluated. In general, the results confirmed the oxygen transfer efficiencies and aeration rates on which the earlier preliminary proposals and feasibility study costs were based. However, peak day and peak hour requirements were neither proposed by the vendors nor estimated during this report. Likewise, the quantities of spent backwash produced by the two units during the pilot testing were similar to the amount predicted by the Krüger in their preliminary design proposal. IDI did not estimate backwash flows in their earlier proposal, however, the pilot test results suggest the Biofor-C and Biostyr are roughly equal in this regard. Therefore, the BAF budget level O&M costs presented earlier are still valid.

Densadeg Process. An earlier design proposal for a full-scale Densadeg system to replace the existing CEPT process was provided by IDI for the above mentioned feasibility study. However, no information on polymer and ferric dose were provided in this proposal. Instead, earlier cost estimates for Densadeg were based on CEPT experience. The pilot testing revealed that this assumption was not valid and that the Densadeg required higher doses of ferric chloride and polymer to provide similar solids removal efficiency as the existing CEPT. The polymer and ferric chloride dosages were as much as 10 and 1.3 times, respectively, the dose of the existing CEPT during the same period. Therefore, the Densadeg O&M costs must be revised upward accordingly if this alternative is to be given further consideration.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions were drawn from Phases I and II of the BAF Pilot Test:

- **Need for Biofor-N**

The Biofor-N was operated in Phase I only. After discovering that the Biofor-C effectively produce effluent that meet secondary effluent limits, the operation of the Biofor-N was discontinued. A comparison of the effluent concentrations and the pertinent standards are shown in the table below.

Para90 meter	Secondary Treatment Standards	Maximum 30-d Running Average Concentration (mg/L)	
	30-d Running Average Concentration (mg/L)	Biofor-C Effluent	Biofor-N Effluent
TBOD ₅	30	21.0 ^(a)	16.7 ^(a)
CBOD ₅	25	12.1	8.8
TSS	30	15.9	9.5

(a) Excludes data collected between March 3 and March 19, 2003, a period when Biofor-N was not fully acclimated and produced effluent with very high TBOD₅.

- **Compliance with Anticipated Regulatory Standards**

1. The pilot testing confirmed that the BAF technology is capable of producing secondary treated effluent that meets anticipated discharge requirements. Both units were able to meet the discharge requirements during simulated wet weather and dry weather conditions. There was one exception to this during Phase I, where the Biostyr unit was unable to meet the TBOD₅ requirement for the last 30 days of operation because Krüger lowered the aeration rate during this period, causing anaerobic conditions to prevail in certain points of the column.
2. The performance of Biostyr and Biofor-C processes did not diminish substantially with the increase in hydraulic, organic, and TSS loading rates over the range tested.
3. The effluent quality produced by the Biofor-C process was better on average than the Biostyr process.

■ TSS, TBOD₅, CBOD₅ and NOD

1. Although the TSS concentration in the effluent from Biostyr and Biofor-C did not exceed secondary effluent limits, it was found to correlate closely with the ability to meet limits associated with TBOD₅.
2. The warm wastewater temperature in San Diego causes the BAF processes to partially nitrify. The presence of nitrifiers and the corresponding 5-day nitrogen oxygen demand (NOD₅) imparted during the TBOD₅ analysis was found to correlate with the amount of TSS in the effluent.
3. The results indicate that meeting the 30-day secondary treatment standard for TSS of 30 mg/L may not equate to meeting the TBOD₅ 30-day average limit of 30 mg/L. For both pilot units, the effluent TBOD₅ exceeded this limit when TSS reached 30 mg/L. Meanwhile, the CBOD₅ concentration is shown to be 10 to 15 mg/L less than the 30-day average limit for CBOD₅ of 25 mg/L.
4. Effluent particulate carbonaceous BOD₅ (pCBOD₅) is the difference between effluent CBOD₅ and effluent SCBOD₅. Dividing pCBOD₅ by effluent TSS concentration gives the particulate pCBOD₅ to TSS ratio. This number is important in understanding the contribution made by the effluent solids to the effluent TBOD₅.

On average, the effluent TSS contribution to effluent CBOD₅ was higher for Biofor-C process (0.29) than for Biostyr (0.23) process. From these average values, the allowable effluent SCBOD₅ concentration was estimated for a series of TSS concentrations using the following relationship:

$$\text{Allowable SCBOD}_5 \text{ in mg/L} = 25 \text{ mg/L CBOD}_5 - (\text{pCBOD}_5:\text{TSS Ratio}) * (\text{TSS})$$

The data showed that as the TSS concentration increases in the BAF effluent, the BAF must be capable of treating soluble CBOD₅ such that the effluent SCBOD₅ cannot exceed 16-18 mg/L under maximum loading conditions. Reducing the effluent TSS concentration, regardless of the TSS effluent limitation, will provide some relief the needed treatment of SCBOD₅.

■ Solids Generation Rate

1. Solids yields in terms of pound TSS produced per pound TBOD₅ removed were higher than expected for both BAF pilot units. Typical values expected for secondary treatment biological systems are 1 pound TSS per pound of TBOD₅ removed. The solids were particularly high in Phase II of the testing when the solids yields for the Biostyr and Biofor-C were calculated to be 1.21 and 1.15, respectively.
2. The results also indicated that a statistically valid difference exists between the two pilot units with regard to solids yield.

3. The difference in yields between the two BAFs are believed to be related to the differences in backwashing procedures. The mini-backwashes used in the Biostyr unit have no analog in the Biofor unit. Krüger uses the mini-backwash to clear influent SS that have clogged the first few inches of the media. As a result, some of the influent SS never penetrate the column and are backwashed directly to the backwash tank. Thus, they never have an opportunity to be biodegraded. This raises the measured yield value for the Biostyr unit relative to the Biofor unit.
4. The study results indicate that the full-scale sludge daily production for the Biostyr and Biofor-C processes could be as much as 166,000 and 169,000 lb TSS/day for Biostyr and Biofor-C units, respectively.

■ Backwash

1. The average backwash to influent flow ratios for the BAFs tested are as follows:

$$\text{Biostyr} = 0.10 - 0.14$$

$$\text{Biofor-C} = 0.07 - 0.08$$

While there is a difference in the backwash steps (i.e., water wash, air scour, water drain, etc.) and the duration of each step, the main difference in backwash volumes may be related to the level of automation of the backwash. The Biostyr pilot unit included features that caused a mini-backwash whenever a setpoint pressure drop was detected across the media; it would still undergo a full backwash at a predetermined frequency (e.g., every 24-hour interval for this study). On the other hand, the Biofor-C backwashed only at the pre-set time interval. The additional backwashes that occurred with the Biostyr when the column was highly loaded with solids added to the overall backwash volume measured.

2. The inability for the Biofor-C column to backwash automatically when highly loaded with solids led to blower failures. Automatic backwash feature controlled by headloss is highly desirable in order to protect the equipment.
3. The calculated Biostyr backwash air scour rate is 44 percent higher than the value proposed by Krüger based on the average of Phase I and Phase II results. The Biofor-C backwash air scour rate based on the pilot test is 5 percent less than the value proposed by IDI. The scour air requirements are not expected to be a major cost driver, but they influence sizing of blowers for the proper capacity.
4. Solids generated by the Biostyr and Biofor-C form an easily separated dense sludge in the Imhoff cone (allowed to settle for 30 minutes).
5. A marked increase in the Sludge Volume Index (SVI) of the backwash water solids occurred between Phase I and II. The difference is most striking for the Biostyr process which went from an average SVI of 30 in Phase I to an SVI of 93 in Phase II. The SVI for the Biofor-C also increased from Phase I to Phase II; however, the increase was not as severe as for the Biostyr. The use of the effluent from the

Densadeg instead of the PLWTP CEPT was the only difference between Phase I and Phase II pilot operation may be the cause in changes observed in the backwash solids characteristics. The increase in SVI could be linked to the different polymer type and the higher chemical doses applied when using Densadeg.

6. The sludge and supernatant from the Imhoff cone experiments were tested for several parameters. The following observations were noted:
 - The supernatant average TBOD₅ values were roughly 2.5 times greater than the CBOD₅ values. In general, the difference between TBOD₅ and CBOD₅ is caused by nitrogenous oxygen demand.
 - The sludge density, measured as total solids (TS) content, varied on average between 0.5 to 2.3 percent in the case of the Biostyr and 0.5 to 1.5 percent for the Biofor-C.
 - The backwash sludge densities decreased from Phase I to Phase II for both BAF pilot units, confirming the changes in SVI. This indicates that a thinner and, perhaps less easily separable sludge particles were produced by the BAFs during Phase II when it was processing effluent from the Densadeg pilot unit.
 - The volatile solids (VS) content of the backwash solids decreased substantially between Phase I and Phase II. This would suggest greater loading of inert solids to the BAF units during Phase II than in Phase I. The lower VS content of the backwash solids produced during Phase II is perhaps connected to the higher ferric chloride dose used for the Densadeg during Phase II.
- **Stressing the BAF System**
 1. Both the Biofor-C and Biostyr processes are robust and able to tolerate shock loading in excess of the design peak-hour Hydraulic Loading Rate (HLR).
 2. Although the target HLRs were selected to simulate various scenarios of units out of service, the actual HLR varied from those selected. The result was that the HLR to the Biostyr unit was about 15 percent higher on average than that for the Biofor-C unit. The Biostyr process did not appear to perform poorly despite the higher loading. In fact, it produced effluent with lower TSS and TBOD₅ concentrations than Biofor-C when loaded at greater than 5.0 gpm/ft². The CBOD₅ effluent concentrations at the higher HLRs were all close to 20 mg/L.
 3. During the trial, a missed backwash for the Biofor-C led to breakthrough of TSS in the effluent. This did not occur with the Biostyr because the Biostyr SCADA system is programmed to backwash the unit automatically when the column headloss reaches a preset target value. This highlights the importance of automated backwashing controls regardless of which BAF process is ultimately selected.
 4. The Biostyr process required considerably more backwash water as a percent of the influent flow than the Biofor-C process. The higher backwash water required implies that higher velocities are required to backwash the Styrofoam media. This

could be necessary to free trapped material with specific gravities close to that of the Styrofoam, which presumably could be carried over from the primary clarifiers into the BAF columns. In addition, Krüger staff indicated that the Biostyr process driver for the intermediate mini-backwashes is to clear accumulation of primary solids that tend to form relatively quickly on the bottom of the media column. This material would otherwise cause excessive headloss over the first few inches of the column. This indicates that in general, primary solids do not penetrate substantially into the Biostyr media bed. Analogous conditions for the Biofor-C have not been identified.

5. The amount of filter area that must be in backwash mode (as a percentage of the total filter area) at any time on average was shown to be greater for the Biofor-C process than for the Biostyr process. Therefore, more backup Biofor-C cells are needed to ensure that there are adequate number of cells in service while cells are backwashing. This is because the Biofor-C (clay media) normally requires more time to backwash than the Biostyr.

■ **Feasibility of Using Dissolved Air Flotation Thickening (DAFT)**

1. Two thickening experiments were performed to determine if DAFT is the appropriate technology for thickening BAF backwash solids. The experiments were as follows:

- Thickening of the BAF backwash solids alone (i.e., dedicated thickening of BAF backwash solids); and
- Thickening of the BAF backwash mixed with primary solids (i.e., co-thickening of BAF and primary solids).

2. Results indicated the following:

■ **Dedicated Thickening of BAF Backwash Water**

- ✓ The sludge removal efficiency was typical for DAFT systems (90 – 95 percent).
- ✓ Sludge TS content obtained in the three trials was substantially lower than the 5.6 percent required to avoid construction of new digesters at PLWTP.
- ✓ To achieve a combined primary and BAF sludge TS content of 5.6 percent, the primary sludge would need to be thickened to 7.1 percent prior to mixing with the DAFT-thickened solids.
- ✓ More analysis is required to either confirm or rule out the feasibility of dedicated DAFT thickening of BAF backwash for PLWTP.

■ **Co-thickening of Blended Primary Sludge and BAF Backwash Water**

- ✓ The sludge removal efficiency was typical for DAFT systems (90 – 95 percent).
- ✓ Sludge TS content obtained in the three trials was marginally in the range needed (i.e., 5.6 percent on average) to avoid construction of new digesters at PLWTP. Based on prior experience with similar sludges, it is likely that with optimization of the float drainage portion of DAFT operation, the desired concentration can be achieved.

■ **Thickening Process Recycle Stream Management**

In a full scale BAF system, it may be possible to manage the recycle stream from the solids thickening operation by commingling it with effluent for ocean disposal. The regulatory status of this scheme is uncertain and would require a favorable interpretation of EPA’s proposed blending policy. On the other hand, EPA could reject this scheme. In this case, the recycle stream would be managed by recycling it to the CEPT influent tunnel downstream of the existing headworks and grit removal facilities. Assuming a favorable interpretation, this would be an option if the combined effluent stream meets the permit limits. The characteristics of the underflow from the DAFT experiments were used to approximate the results of commingling the recycle stream with the BAF effluent. Some findings are provided below.

1. Under dedicated thickening of the BAF backwash, the effluent TSS and CBOD₅ of the underflow and BAF effluent mixture were below the 30-day average permit limits for these parameters. However, the mixture with Biostyr effluent was very close to the TSS limit.

BAF Unit	Effluent Quality Before Thickening Process Recycle Stream Addition (mg/L)	Effluent Quality After Thickening Process Recycle Stream Addition (mg/L)	Effluent 30-d Discharge Limits (mg/L)
Biostyr	CBOD ₅ = 10 TSS= 23	CBOD ₅ = 12 TSS= 29	CBOD ₅ = 25 TSS= 30
Biofor-C	CBOD ₅ = 7.5 TSS= 13	CBOD ₅ = 9 TSS= 17	

2. Under the co-thickening scenario, the underflow is of lower quality such that the mixture of the Biostyr effluent and the underflow exceeds the permit limit for TSS. Combining with a Biofor-C effluent, however, meets the criteria.

BAF Unit	Effluent Quality Before Thickening Process Recycle Stream Addition (mg/L)	Effluent Quality After Thickening Process Recycle Stream Addition (mg/L)	Effluent 30-d Discharge Limits (mg/L)
Biostyr	CBOD ₅ = 10 TSS= 23	CBOD ₅ = 15 TSS= 39	CBOD ₅ = 25 TSS= 30
Biofor-C	CBOD ₅ = 7.5 TSS= 13	CBOD ₅ = 11 TSS= 24	

3. Biostyr effluent quality is not adequate to absorb the recycle stream solids and reliably meet anticipated TSS effluent limit.
4. Biofor-C effluent offers more flexibility in the thickening process selected, i.e., dedicated or co-thickening.
5. High rate filters can be used to remove solids from the recycle stream to improve the feasibility of adding the recycle stream to the BAF effluent for direct discharge to the ocean. This would eliminate the additional hydraulic load imposed by the recycle stream.

■ **Oxygen Transfer Efficiency (OTE)**

1. The off-gas test indicated that the oxygen transfer efficiencies in the two units were comparable to typical fine-bubble aeration systems treating similar flows at similar depths.
2. The calculated OTE values for the full-scale Biofor-C and Biostyr units agree with the OTE curve calculated from the off-gas tests. The full-scale aeration airflow reported in each proposal appears reasonable.

■ **Air Requirements**

1. Based on the pilot test, full-scale system process air requirement at peak month condition was estimated as 52,457 and 74,560 scfm for Biofor-C and Biostyr, respectively.
2. Maximum day and maximum hour air requirements have not been previously evaluated; this must be performed during preliminary design.

■ **Fate of Phosphorus in the BAF**

1. Analysis of BAF influent showed that the average TBOD₅ concentration was typically <100 mg/L. Stabilization of this level of TBOD₅ requires approximately 1 mg/L phosphorus. The average primary effluent (BAF influent) total phosphorus

(TP) concentration during Phase I was 2-3 mg/L, indicating that there should have been sufficient phosphorus nutrient present in the BAF influent flow.

2. Relatively low dissolved oxygen concentrations measured in the lower reaches of the BAFs suggested that the biofilm may have had pockets of anaerobic activity. Observations of black deposits in the biofilm also indicate anaerobic activity. Biological phosphorus release can be expected to occur in anaerobic environments. It is possible that this mechanism may have contributed sufficient orthophosphate to prevent phosphorus nutrient deficiency from occurring.

■ **Bacteria and Virus Removal**

1. The results indicate that the BAF pilot units provided between a 0.48 and 2.55 Log₁₀-removal of bacteria and between a 0.21 and 0.82 Log₁₀-removal of the coliphage virus.
2. During Phase I the Biostyr system outperformed Biofor C by providing on average a 2.55 Log₁₀-removal of total coliform as compared to the 0.96 Log₁₀-removal achieved by Biofor C.
3. During Phase II, however, the Biofor C system performed best. Results of Phase II data show that on average the Biofor C system provided a 1.70 Log₁₀-removal of total coliform as compared to the 1.15 Log₁₀-removal achieved by Biostyr. The data and operational records were carefully reviewed in an effort to ascertain the cause for the reversal. No clear reasons were found.
4. Bacteria samples taken of the receiving waters indicate that the City has been 100 percent compliant with the requirements of the NPDES permit ever since 1993 with the exception of periods after heavy rainfall when storm water runoff caused the shoreline areas to be out of compliance (this is not in any way related to the discharge from the PLWTP). The BAF pilot test results indicate that the addition of BAF treatment at the PLWTP would further reduce effluent bacteria levels by 0.48 to 2.55 Log₁₀.

■ **Toxicity of BAF Effluent from the PLWTP**

Toxicity of both Biostyr and Biofor-C effluents were below PLWTP NPDES permit limits.

■ **Biomass Evaluation**

1. The microscopic assessment of samples of the spent backwash solids revealed the presence living higher life-forms (e.g., stalked and swimming ciliates, rotifers and worms) in both Biofor-C and Biostyr samples. In general, this is seen as evidence that aerobic conditions prevailed in at least portions of the media beds of these units, although it was likely anaerobic conditions also existed in portions of the units.

2. The task of obtaining relatively undisturbed samples at discrete depths from each of the pilot columns proved to be difficult. BAF suppliers were not able to supply equipment or methods for this activity and new methods had to be developed during the project. Various sampler designs were considered and all but one failed to produce results. Media samples were only obtainable from the Biostyr pilot unit and not from the Biofor-C unit. Apparently, the lighter, spherical, and relatively smooth Styrofoam media beads were easier to draw up into the sampler than the clay media; which was angular, non-uniform, heavy, and abrasive by comparison. Because of improper seals, the sampling tool also did not allow the differentiation between the loose bound, or interstitial biomass, versus the firmly bound variety.

3. Analyzing the bound fraction of the biomass proved to be challenging as well. Throughout the pilot test, BC attempted several times to obtain a protocol for testing the biomass. Neither vendor had a proven protocol. Based on past experience with other fixed film technologies, a protocol was developed, but was never tried or optimized. As a result, the estimates based on the analysis indicated that columns had greater biofilm solids inventories after the units were backwashed than they did before the backwash. Since this is not likely to be the case, these results were regarded as erroneous. Since media sampling and analysis was given a lower priority than all other tests performed during the study, time had expired before another media sampling attempt could be made. It would be desirable to resume this effort if the City decides to resume additional BAF pilot testing in the future.

The following conclusions regarding the Densadeg system are based on Phase II of the study:

■ **Densadeg Performance**

1. In general, the existing CEPT system was superior to the Densadeg system for TSS removal but not for SBOD₅ and COD removals. CEPT and Densadeg pilot unit demonstrated similar TBOD₅ removals.

Parameter	Average Removal Efficiencies (%)	
	CEPT	Densadeg
TSS	86	81
TBOD ₅	59	64
SBOD ₅	7	6
COD	60	68

2. The Densadeg unit produced much thicker sludge than CEPT. Densadeg sludge solids content ranged from 2 to 11 percent; and the solids content of the CEPT sludge varied in the range from 3.3 to 6 percent. Average CEPT and Densadeg sludge solid content was 4 and 7.4 percent, respectively.

■ **Impact of De-gritted Raw Wastewater on Performance**

Due to concerns that the full-scale Densadeg will receive de-gritted raw wastewater, a small Eutek Teacup Degritting system was installed after a few weeks of Densadeg operation. The data before and after the installation of the grit was statistically compared to determine if the installation made a difference. However, due to several changes made to the operation, such as chemical feed rates, statistical comparison was inconclusive. The data did show, however, that with the grit removal system, the average TSS loading to the Densadeg unit decreased by 20 percent from 41 lb/ft²-d to 33 lb/ft²-d on average.

■ **Impact of HLR on Performance**

1. The Densadeg pilot unit was operated at an average HLR of 10.10 gpm/ft², which is 98.5 percent of the targeted maximum monthly flow (MMF) condition of 10.25 gpm/ft². At this HLR, the average TSS, TBOD₅ and CBOD₅ removal efficiency achieved by the unit Densadeg was 82, 64, and 54 percent, respectively. Ortho-phosphorus removal in the Densadeg unit was about 95 percent, all by virtue of ferric chloride addition at 40 mg/L.
2. The results indicated that Densadeg unit at the rate of 10.10 gpm/ft² can be used for primary treatment, phosphorus removal, and thickening. However, it required 10 times more polymer and 30% more ferric chloride to achieve nearly the same effluent quality as the existing PLWTP CEPT.
3. At a HLR of 12.23 gpm/ft² (a rate corresponding to 98.6 percent of the full-scale PWWF, or 426 mgd), the average TSS, TBOD₅ and CBOD₅ removal efficiencies were 84, 61 and 54 percent, respectively. This corresponds to average Densadeg effluent TSS, TBOD₅ and CBOD₅ concentrations of 47, 90 and 77 mg/L. This performance was achieved at the same ferric chloride, but slightly higher polymer dosage than used during the trials at 10.10 gpm/ft² HLR described above.

■ **Impact of TSS Loading Rate on Performance**

The average TSS loading rate applied to Densadeg unit was 33 lb/ft²-d; the resulting average effluent TSS concentration was 49 mg/L. Increased solids loading does not appear to cause an increase in effluent TSS concentration. The Densadeg unit was able to process a solids loading rate as high as 44 lb/ft²-d.

■ **Effect of Co-Settling on Densadeg Performance**

According to the two co-settling tests performed, it appears that co-settling of backwash water did not cause an upset in Densadeg unit operation in terms of TSS, TBOD₅ and CBOD₅. The effluent quality was in the range of normal operation values. Note that this result cannot be interpreted as confirming the practice of co-settling the BAF backwash as a viable option for PLWTP. The only conclusion that can be drawn is that limited recycling of backwash to the Densadeg did not appear to

produce upsets. The experiment did not reflect full-scale recycling because there was not enough backwash water produced by the BAF units for a representative experiment. Had the limited backwash experiment shown an upset, then it could have been inferred that upsets would be likely occur in a full-scale system.

■ **Operational Requirements**

1. Densadeg unit required addition of ferric chloride and polymer to enhance the settling characteristics of the raw wastewater.
2. Ferric Chloride. Target ferric addition at the Densadeg unit was 40 mg per liter of wastewater both at HLR of 10.25 and 12.4 gpm/ft². Actual ferric consumption was monitored daily. According to readings, actual ferric consumption at Densadeg was about 42 mg/L.
3. Polymer. At a HLR of 10.25 gpm/ft², the actual active polymer consumption was about 1.3 mg/L.
4. Sludge Blanket Level. A constant sludge blanket level needs to be maintained for steady state Densadeg performance. The target sludge blanket level was 3 to 4 feet for the Densadeg pilot unit. Sludge wasting rate needs to be adjusted depending on the incoming wastewater quality to achieve the target sludge blanket level.
5. Solids Wasting Rate. Sludge wasting rate was adjusted manually to achieve the target sludge blanket level at the Densadeg pilot unit. Sometimes sludge blanket level dropped to as low as 1 foot due to operational problems. In these instances, sludge wastage was minimized to build up enough sludge level in Densadeg unit. Time between sludge blowdown events ranged in between 0.2 to 10 hours. It was 0.6 hours on average. Sludge wastage lasted 34 seconds on average, although it varied in between 5 to 60 seconds.
6. The Densadeg system appeared to be more sensitive to diurnal and seasonal (wet weather) changes in wastewater characteristics than the existing CEPT process, leading to frequent process upsets. Some of these would, perhaps, have been mitigated if the pilot unit were equipped with automated process controls.
7. In a full-scale application of the Densadeg at PLWTP, the pilot test experience suggests it is critical to include an automated chemical feed system. Such an automated system should be flow-paced and perhaps solids mass-flow paced using online measurement of suspended solids content.
8. Automated controls to vary wasting rate based on sludge blanket depth is important to consistent performance. IDI indicated that full-scale systems include sonic sludge blanket level sensors used to control sludge blanket level. It is not clear how the entire balance of process components described above would be automated to reduce the need for constant operator attention. Under the best circumstances, a

highly skilled instrumentation and controls team would be needed to maintain the control components.

■ **Cost Implications of Study Results**

1. In June 2003, BC submitted a draft report assessing the feasibility and requirements of upgrading the PLWTP with BAF secondary treatment. This report included the preliminary design proposals that were generated by the manufacturers. The design was based on the vendor's standard performance assumptions. Site-specific pilot trials on the PLWTP wastewater had not been performed at the time of the vendor's proposals. Budget level cost estimates were prepared and presented in that report pending verification of process performance through pilot testing. Listed below are impacts of the pilot study findings on the earlier costs estimates.
2. Regardless of the pilot study results, recent escalation of material costs—primarily the costs of steel, fuel, and concrete—will likely increase the capital cost required for the proposed BAF and solids handling facilities above what was estimated previously in 2003. BC therefore recommends new cost estimates to be calculated as part of a preliminary design effort should the City go forward with plans to provide full secondary treatment at PLWTP.

■ **Impacts on Capital Cost Estimates**

- ✓ In general, each of the BAF pilot unit met performance requirements under simulated hydraulic and organic loading conditions mentioned above. Therefore, design loading assumptions that formed the basis of facility sizing in the original full-scale proposals were verified. Moreover, the results indicate that the proposed media column height for Biostyr could even be reduced without compromising the ability to meet regulatory limits, even at peak hydraulic loading conditions.
- ✓ The estimates for the Biofor system must be adjusted to reflect the need for a single stage system only, i.e., the Biofor-N stage is not need to meet the anticipated secondary treatment standards.
- ✓ Although the pilot test validated the assumptions leading to the earlier cost estimates, recent escalation of material costs will likely increase the capital cost required for the proposed BAF facilities above that which was previously estimated
- ✓ The reason higher solids yield for the BAF processes tested than anticipated may be due to post precipitation of iron compounds. It is prudent to plan and develop budget level cost estimates based on the pilot study results to avoid the potential shortfall in land and funding should the actual yield be accurately depicted by the level derived from the pilot study. During predesign, agencies operating full-scale facilities could be contacted for data

to determine if similar yield rates are observed. The cost estimates could then be refined at that stage.

- ✓ The results of the Densadeg pilot testing confirmed that the design hydraulic loadings used in the earlier design proposal by IDI were valid for the Densadeg. However, it was learned that the complexity and potential sensitivity of the Densadeg to fluctuations in wastewater quality may not be suitable for full-scale application at PLWT given the relatively simplicity and effectiveness of the existing CEPT process. Should the City be inclined to replace CEPT with Densadeg in the future as a space saving measure, the capital costs estimated in the earlier proposal and feasibility report for the Densadeg appear to be valid based on the pilot test results.

- **Impact on O&M Cost Estimates**

- ✓ In general, the results confirmed the oxygen transfer efficiencies and aeration rates on which the earlier preliminary proposals and feasibility study costs were based. However, peak day and peak hour requirements were neither proposed by the vendors nor estimated during this report. Likewise, the quantities of spent backwash produced by the two units during the pilot testing were similar to the amount predicted by the Krüger in their preliminary design proposal. IDI did not estimate backwash flows in their earlier proposal, however, the pilot test results suggest the Biofor-C and Biostyr are roughly equal in this regard. Therefore, the BAF budget level O&M costs presented earlier are still valid.
- ✓ Earlier cost estimates for Densadeg were based on CEPT experience. The pilot testing revealed that this assumption was not valid and that the Densadeg required higher doses of ferric chloride and polymer to provide similar solids removal efficiency as the existing CEPT. The polymer and ferric chloride dosages were as much as 10 and 1.3 times, respectively, higher than the dose of the existing CEPT during the same period. Therefore, the Densadeg O&M costs must be revised upward accordingly if this alternative is to be given further consideration.

Recommendations

The following tests should be implemented to further evaluate the potential of BAF to provide full secondary treatment at PLWTP:

- **BAF**

1. **Automation of the BAF** - The BAF pilot study experience suggested that proper automation of the BAF process is essential to the systems consistent compliance with anticipated regulatory limits. This was exemplified during stress testing when

the lack of automation on the Biofor-C unit led to a missed backwash, blower failure and subsequent TSS breakthrough. BC recommends surveying municipalities that operate full scale BAF facilities to investigate the types of automated control strategies in use at these installations as well as the historical success and failure rates associated with these strategies.

2. **Addition of Media Pressure Sensors** - During the pilot testing, the use of pressure sensors at intermediate depths in the media bed proved to be a good diagnostic tool for understanding the buildup of pressure within the columns. This type of intermediate pressure monitoring would be of value in a full-scale system as well. A cost/benefit analysis of such a system is advisable should the City pursue construction of a full-scale BAF system.
 3. **Media Sampling and Testing** – Media sampling was intended to provide the insight into the BAF biomass characteristics that would be useful, both from the perspective of process control and to explain the differences in performance of different types of media and process configurations. The suppliers were not able to provide techniques for sampling, so they had to be developed during the pilot project and only limited success was achieved only late in the program. The limited results obtained were indeed valuable. It is recommended that media sampling experiments be conducted at existing BAF facilities so that permanent facilities can be incorporated into the full-scale design.
- **Solids Processing**
1. **Re-evaluation of Solids Processing Strategies** - The solids generation that was measured during the pilot test was higher than previously assumed. Therefore, solids process alternatives for the full-scale design should be re-evaluated including evaluation of the sufficiency of available digester capacity related to the solids generation rates measured during the pilot testing. New cost estimates should also reflect the increased solids generation.
 2. **Evaluation of Thickening Alternatives** - Limited thickening experiments were conducted during the pilot study (e.g., bench scale DAFT and limited co-settling experiments). However, these were not the comprehensive solids processing studies that should be conducted prior to full-scale design. Therefore, additional solids process pilot testing is recommended considering the importance of the solids component in the full-scale design and associated costs. Such pilot testing might include arranging for trailer mounted units (e.g., centrifuge, gravity belt thickeners, DAFTs, etc.) to be tested at an existing BAF installation employing CEPT. Failing this, the testing completed to date are believed to be sufficient to prove the viability of DAFT technology for use as a co-thickening device, as the results obtained are similar to those obtained at other sites with co-thickening of raw and biological sludges.

- **High Rate Calrification/Thickening (HRCT)**
 1. **Densadeg Re-test** – It was observed during visits to full-scale HRCT systems in Minnesota and Europe that such systems provided compact primary clarification and consistent performance. HRCT provides the necessary primary treatment at a reduced footprint – a key advantage if space is limited. The pilot testing of the Densadeg was inconclusive with regard to feasibility of a full-scale system. This was due to the many process upsets that were encountered during the pilot testing. IDI has indicated that these problems would have been avoided if the process automation used on full-scale Densadeg installations were available for the pilot scale unit. If IDI can reconfigure a Densadeg pilot unit with the same automated controls and solids inventory control features that are standard on full-scale systems, it would be worth pilot testing that unit again to better evaluate the process for PLWTP.
 2. **Densadeg as a Thickener** - The Densadeg exhibited the ability to produce sludges with up to 11 percent total solids content. Therefore, it would be worth pilot testing Densadeg as a thickening device at a full-scale BAF facility employing CEPT. For this test to be useful, the climatic conditions would have to similar to those prevailing in San Diego.

- **Other Technologies**
 1. **Evaluation of Other Emerging Secondary Treatment Technologies for Constrained Sites** - In addition, the City should continue to track emerging compact treatment technology including some of those listed in Appendix A (e.g., membrane bioreactors, moving bed biofilm reactors, integrated fixed film activated sludge, and submerged biological contactors). Emerging companies supplying alternative BAF systems at large plants should also be sought and tracked. Tours to existing full-scale installations of these technologies are also worth pursuing. Continuing to develop a solid base of understanding of new technologies is the best way to keep a variety of options open to the City as it moves forward with planning for a full-secondary treatment system at the PLWTP. Pilot testing of new technology (such as those listed in Appendix A) should be considered when practical.
 2. **Pilot Testing of Evaluation of Disinfection Technologies** - Since pathogen removal could become an important consideration in the future both in terms of public perceptions and as a regulatory requirement, additional evaluations of the efficacy of disinfection technologies such as UV on BAF effluent should be conducted.

- **Cost Estimates**

Re-evaluation of Cost Estimates – The cost estimates should be re-evaluated in light of the pilot test results and the increased material costs that have manifested since the last cost estimate. Prior to the cost estimates, solids processing alternatives should be re-evaluated given the results of the pilot testing. Further, the land acquisition issue should be resolved, and a preliminary geotechnical investigation should be performed.

- **Permitting**

CBOD₅ Permit Limit - To protect the City from analytical or operational problems that cause NOD₅ to be exerted within the five day BOD test upon committing to secondary treatment for all or part of the flow to the PLWTP, permit applications should be for CBOD₅ rather than TBOD₅.