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WACS 39859



**ENVIRONMENTAL, INC.**  
An Affiliate of the Black Clawson Co.

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Telephone (715) 359-7211  
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December 13, 1994

Citrus County Solids Waste Management  
P.O. Box 340  
Lecanto, FL 34460-0340

Attention: Ms. Susan Metcalfe, P.G.

Reference: Leachate Treatment Plant Modification  
DEP Letter Dated 12-9-94

Dear Ms. Metcalfe:

We received a copy of the subject letter via telefax and offer the following in support of your response on this permit modification issue:

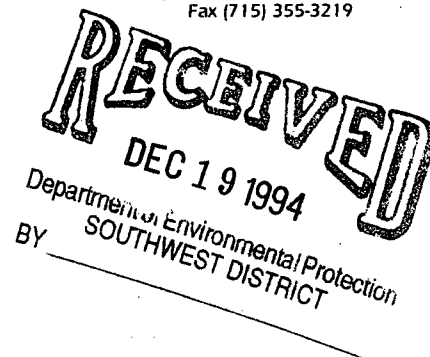
1. Enclosed is operating data from two PACT® wastewater treatment plants that were designed to accomplish carbonaceous BOD removal and nitrification in the first stage and to denitrify in the second stage, i.e. El Paso, TX. (Appendix A) and Hillsborough Co., FL (Appendix B). Both plants are continuous flow, two stage plants. Each plant uses carbon in both stages, virgin carbon is fed to the second stage and this gets "wasted" to the first stage. Methanol is used as the carbon source in the second stage of each plant in order to achieve efficient denitrification. The plant at El Paso, TX has been on line for over eight years and is a ten million gallon per day facility. The plant at Hillsborough County, FL. has recently been put on line and is currently treating about 60,000 gallons per day of leachate from an ash monofill landfill.

As can be seen from the data, both facilities are nitrifying completely and denitrifying to very low levels.

We see no reason why two stage nitrification/denitrification cannot be accomplished in an SBR. We have operated several bench-scale pilots plants in this mod and have achieved essentially complete nitrogen removal.

Also, Zimpro has not experienced any difficulty nitrifying with any SBR PACT®. Data from the BFI leachate treatment facility (Appendix C) has characteristics similar to Citrus County's and nitrifies very efficiently. (Once nitrified, the waste can easily be denitrified).

2. Elevated levels of TDS can affect any biological treatment process. The concentration of TDS present at the Citrus County facility are not cause for concern. The attached data



**PRELIMINARY DESIGN MEMORANDUM FOR  
FDEP CONSTRUCTION PERMIT**

**Owner:**

Citrus County  
Department of Public Works  
Division of Solid Waste Management  
230 W. Gulf to Lake Highway  
Lecanto, FL 34460  
(904) 746-5000



**Existing Facility:**

Citrus County Landfill  
Leachate Treatment Plant

**Request:**

Modification of FDEP Operation Permit No. SO 09-187229 for construction approval to implement process improvements for increased nitrate removal.

**Reason:**

Modification of existing Leachate Treatment Plant is proposed to achieve acceptable nitrate levels in the discharge to the permit standard of 12 mg/l.

The leachate treatment plant was designed for a BOD<sub>5</sub> of 2,000 mg/l and an NH<sub>3</sub> of 400 mg/l. The influent characteristics of the leachate is different than expected at the time of design, particularly the BOD<sub>5</sub> at significantly reduced level of less than 200 mg/l. The reduced carbon (BOD<sub>5</sub>) levels has hindered the nitrate removal phase by limiting the carbon necessary to allow denitrification to proceed during the anoxic mode. The modification will consist of conversion of the three parallel reactors to a two stage aeration system. The first stage (Reactors No. 1 and 2) will remain a sequencing batch reactor with fill, aeration, anoxic, settling and decant modes. The second stage will be converted to a sequencing batch anoxic reactor with the addition of a supplemental carbon source (methanol) for efficient denitrification. The second stage will be an anoxic mode modified with improved mixing to allow more complete mixing.

**Existing Process:**

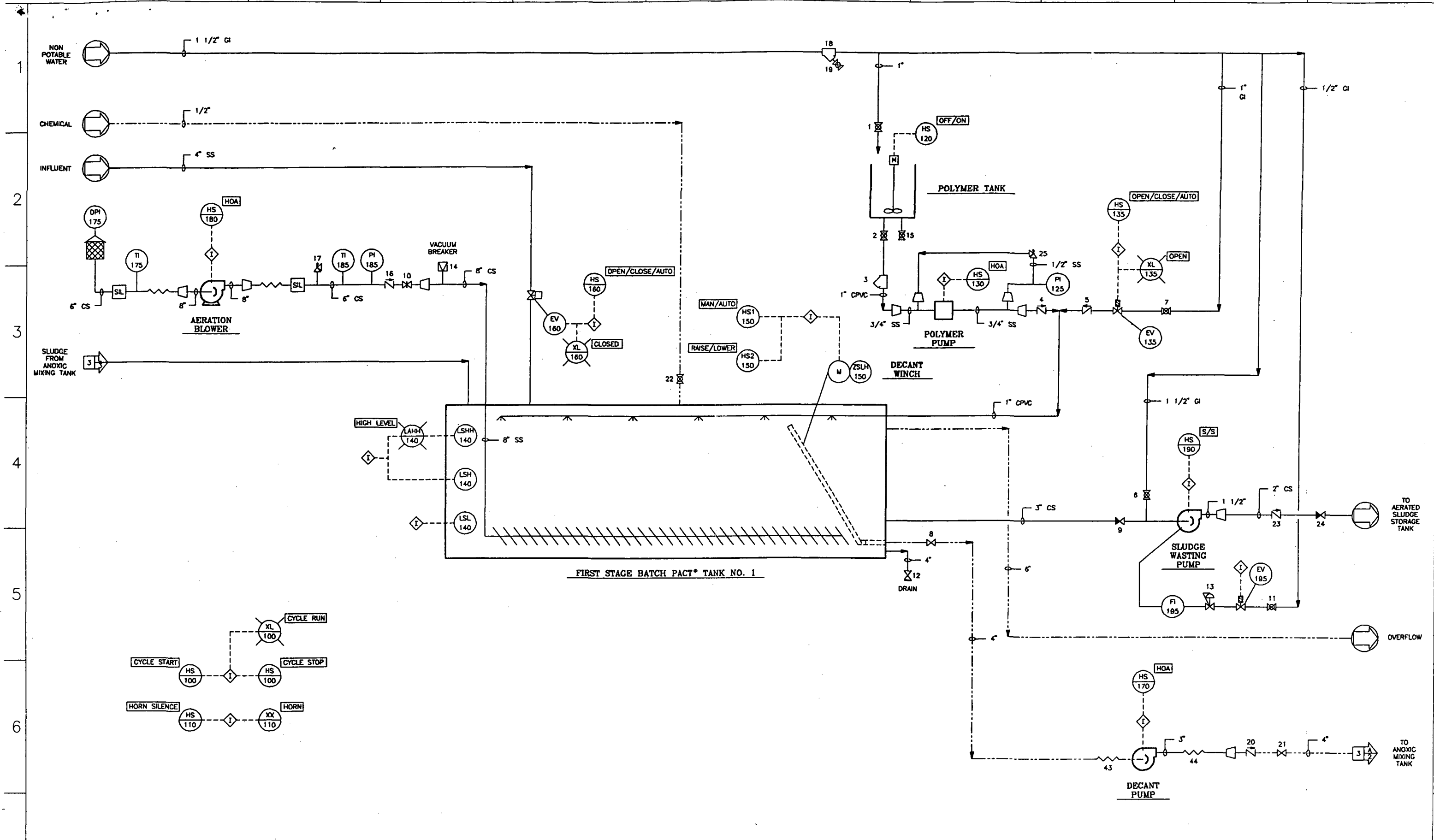
The existing leachate treatment facility of three parallel Zimpro powered activated carbon reactor tanks followed by a tertiary sand filter. Each reactor tank is a sequencing batch reactor consisting of process modes for fill, aeration, anoxic mixing (denitrification), settling and decant.

**PRELIMINARY DESIGN MEMORANDUM FOR  
FDEP CONSTRUCTION PERMIT (CONTINUED)**

**Process Modification:**

The revised leachate treatment facility will consist of a first stage (Reactor No. 1 and 2) powered activated carbon sequencing batch reactor and a second stage (Reactor No. 3) powered activated carbon anoxic batch reactor.

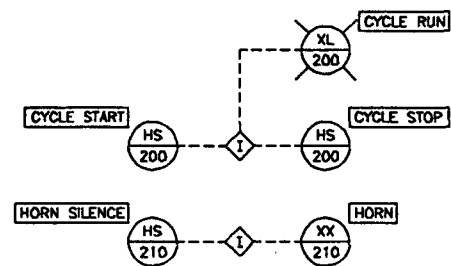
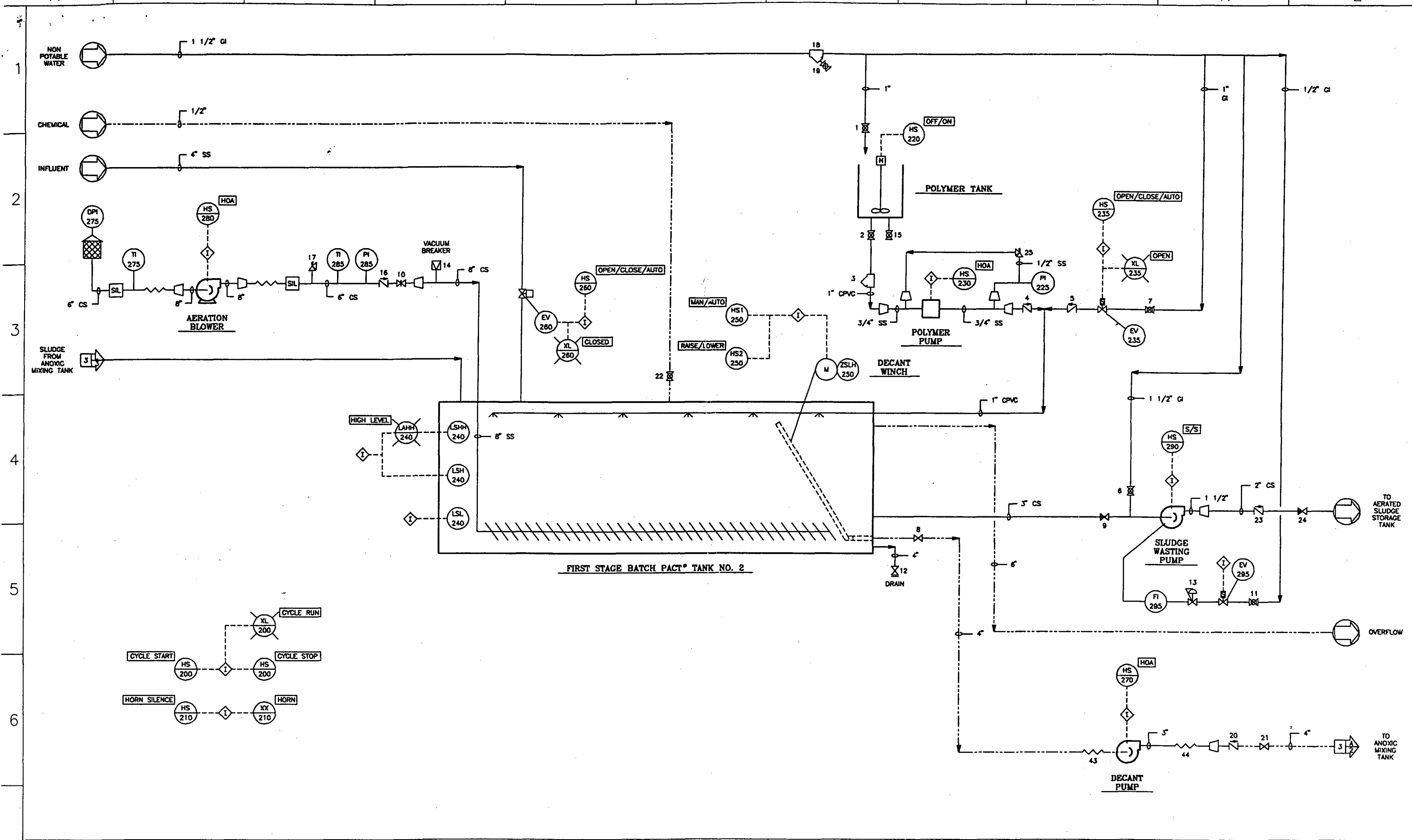
1. Convert Aeration Reactor No. 3 to a second stage reactor. Reroute discharge from Reactors No. 1 and 2 to Reactor No. 3 (see attached Drawing 1 of 4 and 2 of 4 with this change). Modify controls for Reactor No. 3.
2. Add three new mixers (3 HP each) to Reactor No. 3 to replace single submersible mixer (see attached Drawing 3 of 4 with this change). Add new access bridge and grating and hand rails.
3. Add methanol storage tank (1700 gal) and methanol feed pumps with piping to Reactor No. 3 (see attached Drawing 4 of 4 with this change).



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**PREFABRICATED MODEL B140 BATCH PACT® LEACHATE TREATMENT SYSTEM FOR CITRUS COUNTY, FLORIDA**

**ENGINEERING FLOW DIAGRAM**

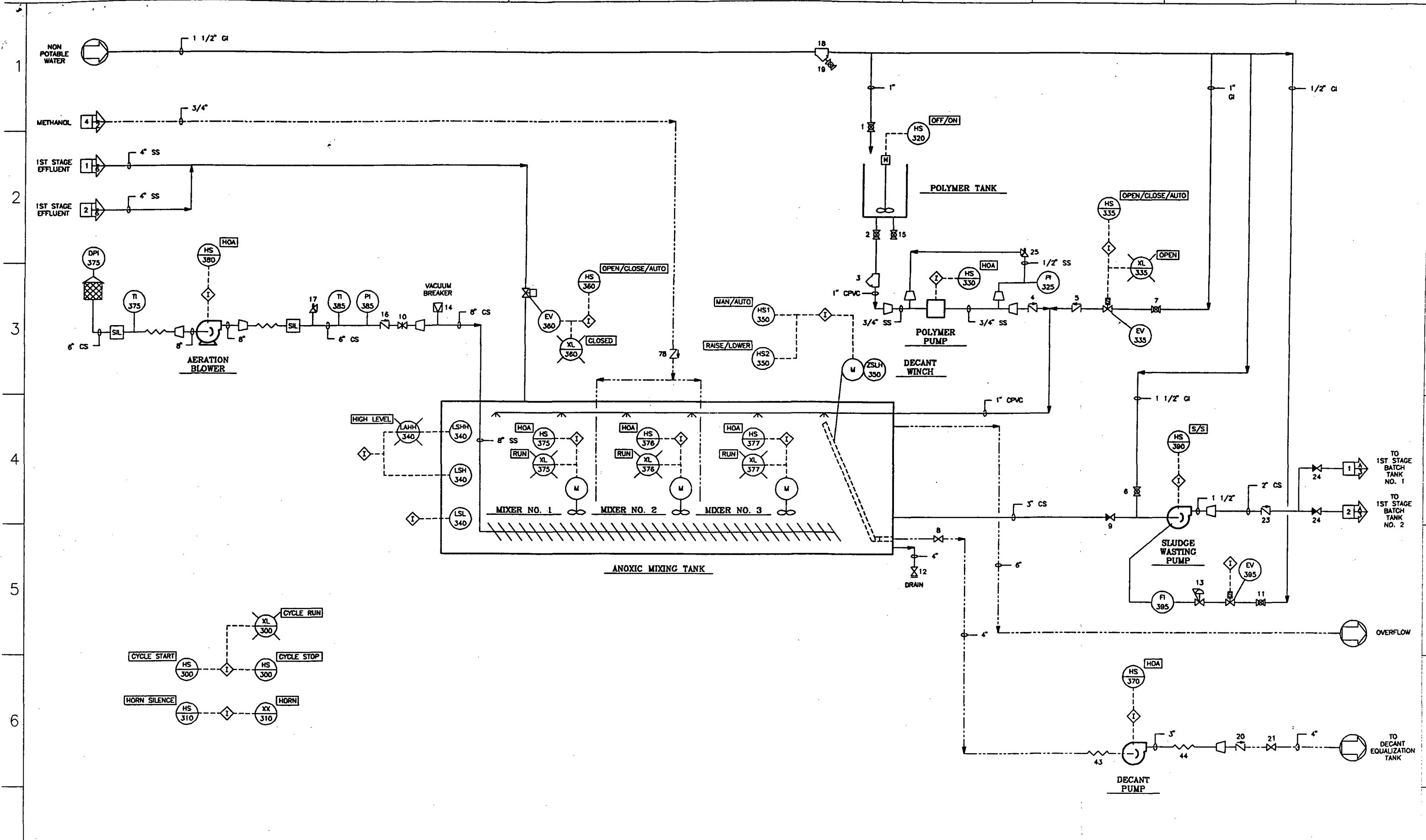
DRAWN	Larry J. Boepke
CHECKED	Larry J. Boepke
APPROVED	David A. Boepke
DATE	10-12-89
DWG. SAVE NAME	CC-EFD2
SCALE	NONE
SHEET	2 OF 4

**ZIMPRO ENVIRONMENTAL, INC.**  
An Affiliate of the Black Clawson Co.

DRAWING NUMBER  
**30.1-2343-D-1003**

REV. **2**

REV.	DATE	BY	DESCRIPTION	CHECKED	APPROVED
2	9-94	LJD	REVISED TO 2 STAGE SYSTEM		



REV.	DATE	BY	DESCRIPTION	CHKD	APPRD
2	9-94	LJD	REVISED TO 2 STAGE SYSTEM		

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**PREFABRICATED MODEL B140 BATCH PACT®**  
**LEACHATE TREATMENT SYSTEM FOR**  
**CITRUS COUNTY, FLORIDA**

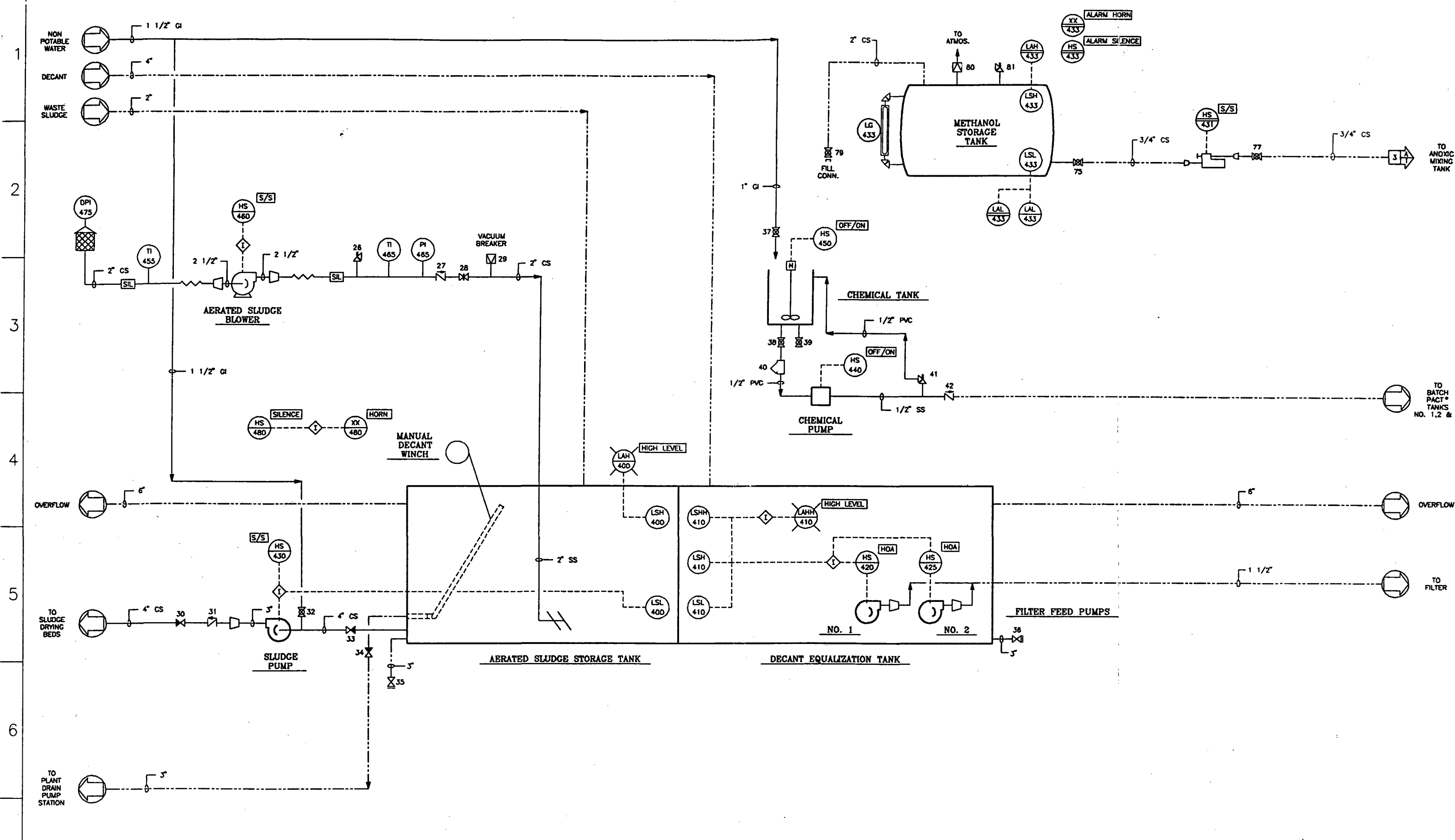
**ENGINEERING FLOW DIAGRAM**

DRAWN	Larry J. Doepke
CHECKED	Larry J. Doepke
APPROVED	David A. Buda
DATE	10-12-89
DWG. SAVE NAME	CC-EFD3
SCALE	NONE
SHEET	3 OF 4

**ZIMPRO**  
**ENVIRONMENTAL, INC.**  
 An Affiliate of the Black Clawson Co.

DRAWING NUMBER  
**30.1-2343-D-1003**

REV. **2**



2	9-94	LJD	REVISED TO 2 STAGE SYSTEM	2024
REV.	DATE	BY	DESCRIPTION	CHECKED APPR'D

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PREFABRICATED MODEL B140 BATCH PACT®  
LEACHATE TREATMENT SYSTEM FOR  
CITRUS COUNTY, FLORIDA

ENGINEERING FLOW DIAGRAM

DRAWN	Larry J. Bosche
CHECKED	Larry J. Bosche
APPROVED	David A. Buda
DATE	10-12-89
DWG. SAVE NAME	CC-EFD4
SCALE	NONE
SHEET	4 OF 4

**ZIMPRO**  
ENVIRONMENTAL, INC.  
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DRAWING NUMBER  
**30.1-2343-D-1003**

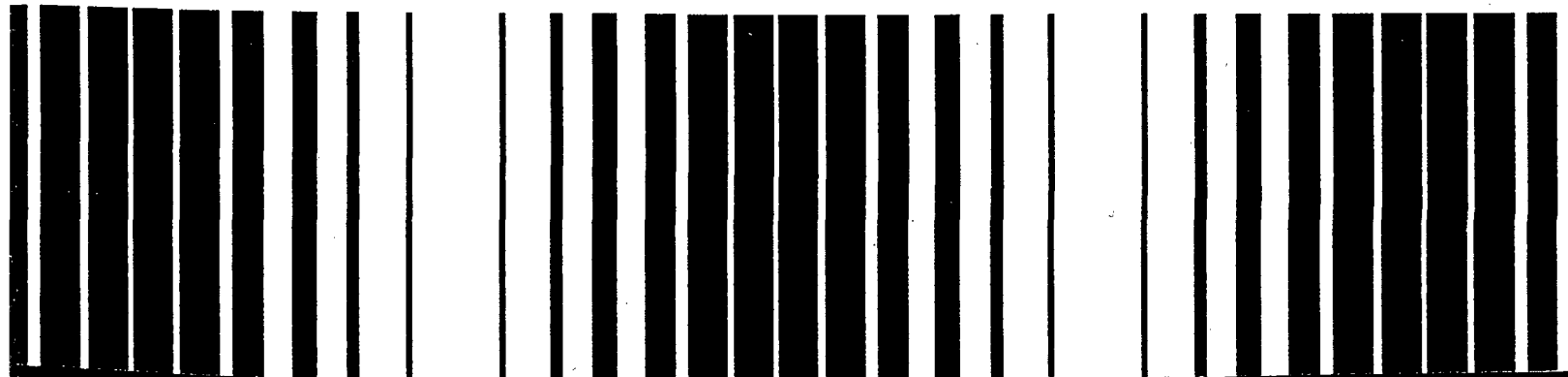
REV  
**2**

D.E.P.  
OCT 14 1994  
SOUTH DISTRICT  
TAMPA



# Manual

## Nitrogen Control



- Under transient conditions of organic shock loading, diffusional resistances and heterotrophic/nitrifier competition can increase the limiting DO value significantly.
- Under transient conditions, nitrite conversion to nitrate can become the rate-limiting step in the nitrification process; in such conditions, the resulting accumulation of nitrite is not correlated to low DO values.

It can be concluded from this study, as well as from other recent (29) and past studies (30), that the intrinsic growth rate of *Nitrosomonas* is not limited at DO concentrations above 1.0 mg/L, but that DO concentrations greater than 2.0 mg/L may be required in practice. When designing the aeration or oxygen addition component of a suspended growth nitrification system, it is recommended that a minimum DO level of 2.0 mg/L be specified at all times throughout the biological reactor to prevent peak load ammonia bleed-through. If significant, occasional transient conditions are anticipated, consideration should be given to providing standby DO capacity.

If mass-transport or diffusional resistances are an inherent characteristic of the nitrification reactor, as is the case with attached growth reactors, the DO level achievable in designing the oxygen addition component should be relatively high. Recent research work suggests that bulk fluid DO levels should be near 70 percent saturation. Lower levels may suggest mass-transfer limitations and limited ventilation (31). These considerations are discussed in more detail in Section 6.5.2.

### 3.3.4 pH and Alkalinity Effects

When the equation describing the complete nitrification process (Equation 3-8) is written in the context of the carbonic acid system, a substantial destruction of alkalinity is implied. It can be shown (4) that over a pH range of approximately 5 to 8 in an aqueous biological reactor, the equilibrium pH of the reactor will be dictated by the amount of alkalinity and  $\text{CO}_2$  present in the system. Higher pH levels can be maintained at lower alkalinity levels in systems in which the stripping of  $\text{CO}_2$  occurs in the biological reactor. Where the stripping of  $\text{CO}_2$  does not occur, as is the case in enclosed systems, the alkalinity of the wastewater must be 10 times greater than the amount of ammonium nitrified in order to maintain a pH greater than 6.0 (32). Recall that the theoretical alkalinity destruction ratio is 7.1 mg (as  $\text{CaCO}_3$ )/mg of ammonium-nitrogen oxidized. The observed alkalinity destruction ratio has generally been equal to or less than the theoretical value in open systems using air as a source of oxygen (4).

Further information on the effect of particular aeration systems on the resulting reactor pH is provided in Section 6.4.10.4. The incorporation of a phosphorus removal capacity into nitrification systems through the addition of chemicals to the reactor(s) will also affect the reactor

alkalinity. Information on this consideration is presented in Section 6.4.10.2 and Table 2-3.

Reactor pH conditions have been found to have a significant effect on the rate of nitrification, as summarized in Figure 3-2. The degree of acclimation to the corresponding pH is also annotated on the figure. A wide range of optimum pH has been reported; an almost universal finding, however, is that as the pH moves to the acid range the rate of ammonium oxidation declines. This tendency has been found to be true for both unacclimated and acclimated cultures, although acclimation, or selection of a different population of organisms with time, tends to moderate pH effects. In one study involving an attached growth reactor, nitrification declined by 50 percent at pH 6.0 after 1.5 d of acclimation, but no decline in nitrification performance was evident after acclimation for 10 d (32). In another study it was found that an abrupt change in reactor pH from 7.2 to 6.4 had no adverse effect on nitrification. However, when the pH was abruptly changed from 7.2 to 5.8, nitrification performance deteriorated markedly as effluent ammonium levels rose from approximately zero to 11 mg/L  $\text{NH}_4^+\text{-N}$ . A return to pH 7.2 caused rapid improvement, indicating that the lower pH was only inhibitory and not toxic (45).

For design purposes, it is sufficient to take into consideration that the nitrification rate may drop significantly as pH is lowered below the neutral range and that for performance stability it is best to maintain pH at 6.5–8.0. The effect of lower pH conditions, if they are anticipated, should not be ignored when sizing nitrification reactors even though acclimation will attenuate the effect of pH on the nitrification rate.

### 3.3.5 Effect of Inhibitors

Nitrifying organisms are susceptible to a wide array of organic and inorganic inhibitors. As pointed out by Stover (46), nitrifiers can adapt to many inhibitory compounds when inhibitors are constantly present in the wastewater versus when slug discharges occur (e.g., from an accidental industrial discharge). Inhibition can occur through interference with the general metabolism of the cell or with the primary oxidative reactions. More important than distinguishing the mechanism of inhibition, however, is the need to establish a methodology for assessing the potential for, or occurrence of, nitrification inhibition in a biological system. Such procedures have been proposed by numerous researchers (46–48). More on design considerations that deal with the issue of nitrification inhibition is provided in Chapter 6 (Section 6.3.1).

Extensive reviews of the influence of selected inorganics and/or organics on nitrification inhibition have been prepared by Neufeld's group (49), Hockenbury and Grady (50), Pantea-Kiser's group (47), and Painter (51). While the data base on nitrification inhibition is extensive, Table 3-4 provides a list of several industrially significant or

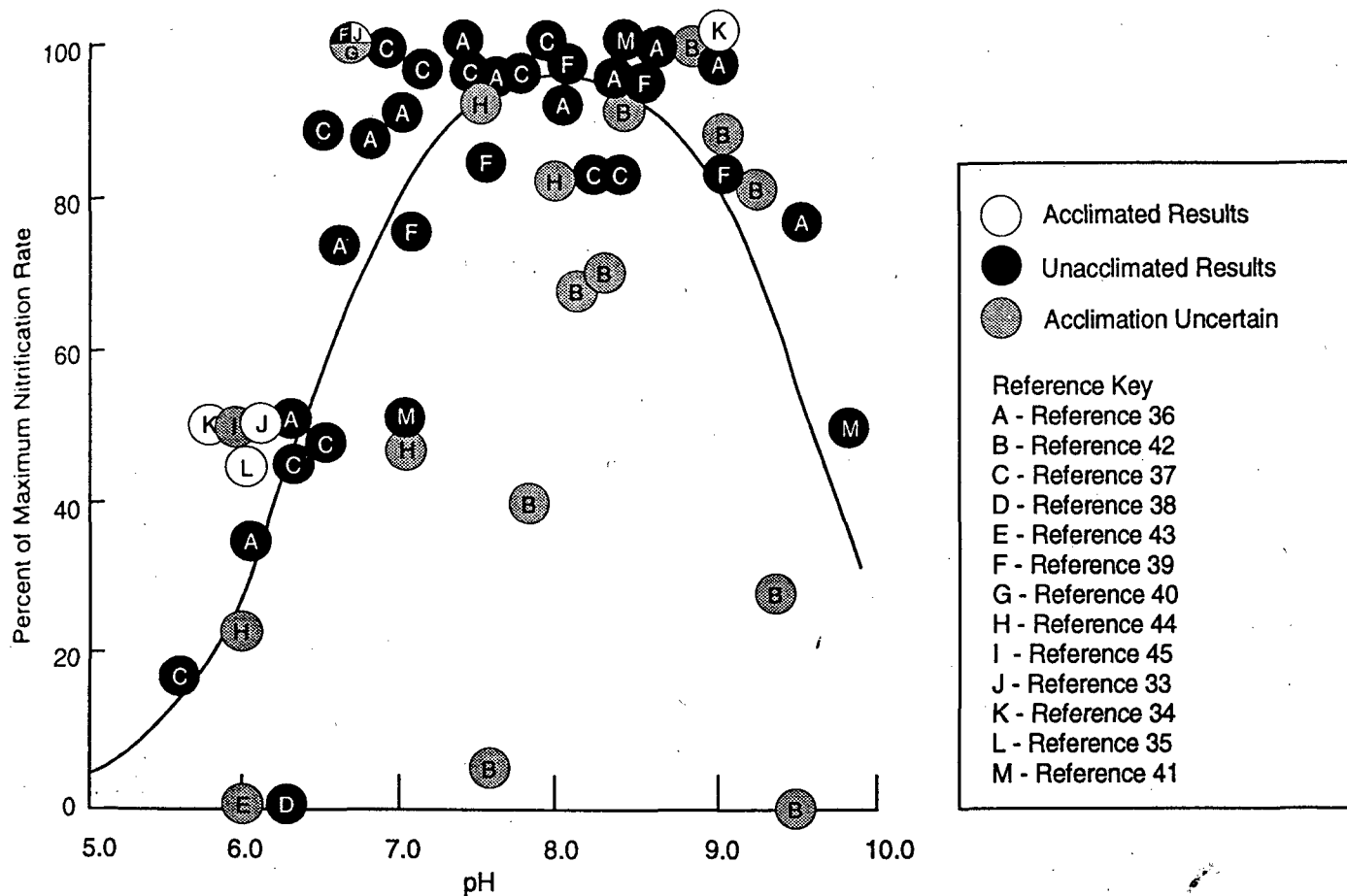


Figure 3-2. Effect of reactor pH conditions on rate of nitrification.

ganic chemicals found to cause some degree of nitrification inhibition. Care must be taken, however, when interpreting reported concentrations of inhibitory compounds, since acclimation can occur and effectively remove the inhibitory effect from a system; in a complete mixed system, the nitrifiers will normally see significantly lower concentrations than present in the influent, and suggested levels are often considerably higher than could occur in typical collection systems, particularly where pretreatment programs are in place. The reported data should be used as references for the relative effect of specific compounds.

Certain inorganics, including specific metals, are inhibitory to nitrifiers. Sawyer, on reviewing studies carried out in England, suggested that 10–20 mg/L of heavy metal

can be tolerated due to low ionic concentrations at pH values of 7.5–8.0. Inorganic compounds identified as potential inhibitors are listed in Table 3-5.

Nitrifying organisms are also sensitive to certain forms of nitrogen. Un-ionized ammonia ( $\text{NH}_3$ ), or free ammonia (FA), and un-ionized nitrous acid ( $\text{HNO}_2$ ), or free nitrous acid (FNA), are believed to be inhibitory to nitrifiers above certain concentrations. FA begins to inhibit *Nitrosomonas* at a concentration of 10–150 mg/L and *Nitrobacter* in the range of 0.1–1.0 mg/L (56). FNA begins to inhibit *Nitrosomonas* and *Nitrobacter* at concentrations of 0.22–2.8 mg/L. The FA and FNA concentrations are directly correlated to pH and temperature, and the concentration, respectively, of ammonia plus ammonium and nitrite plus

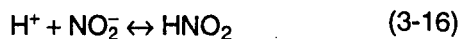
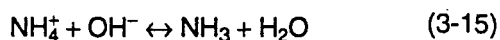
**Table 3-4. Industrially Significant Organic Compounds Inhibiting Nitrification (Adapted from Reference 50)**

Compound	Concentration of Compound Giving at Least 50 Percent Inhibition, mg/L
Acetone	2,000
Carbon disulfide	38
Chloroform	18
Ethanol	2,400
Phenol	5.6
Ethylenediamine	17
Hexamethylene diamine	85
Aniline	<1
Monoethanolamine	<200

**Table 3-5. Metals and Inorganic Compounds Identified as Potential Nitrification Inhibitors**

Compound	References
Zinc	1, 51
Free Cyanide	49
Perchlorate	1
Copper	1, 54
Mercury	1
Chromium	1, 53, 55
Nickel	1, 52, 54, 55
Silver	1
Cobalt	51
Thiocyanate	49
Sodium cyanide	52
Sodium azide	52
Hydrazine	52
Sodium cyanate	52
Potassium chromate	52
Cadmium	54
Arsenic (trivalent)	53
Fluoride	53
Lead	55

nitrous acid. FA and FNA are present in accordance with the following equilibrium reactions:



Threshold levels of ammonia plus ammonium-nitrogen, and nitrite plus nitrous acid-nitrogen at which nitrification inhibition may begin at a pH of 7.0 and a temperature of 20°C (68°F) are presented in Table 3-6 for illustrative purposes. (Values for other pH and temperature condi-

**Table 3-6. Calculated Threshold Values of Ammonia Plus Ammonium-Nitrogen and Nitrite Plus Nitrous Acid-Nitrogen Where Nitrification Inhibition May Begin (from Reference 56)**

Inhibitory FA or FNA Concentration, mg/L	Equivalent Ammonia plus Ammonium-N at pH 7.0 and 20°C, mg/L	Equivalent Nitrite plus Nitrous Acid-N at pH 7.0 and 20°C, mg/L
FA		
10 ( <i>Nitrosomonas</i> Inhibition)	1,000	—
0.1 ( <i>Nitrobacter</i> Inhibition)	20	—
FNA		
0.22 (Nitrification Inhibition)	—	280

tions can be calculated [56].) The calculated values imply that it is unlikely that nitrification inhibition will occur as a result of the presence of ammonia plus ammonium and nitrite plus nitrous acid in the treatment of typical municipal wastewaters. However, sludge discharges into municipal systems of highly concentrated industrial wastes containing these forms of nitrogen can cause inhibition.

If anaerobic digestion is incorporated into a wastewater treatment plant and if untreated supernatant is returned to the process, a suitable reduction in the nitrification rate should be made. The growth rate of *Nitrosomonas* in a suspended growth reactor treating municipal wastewater can be inhibited by introduction of digester supernatant, according to Gujer (57) and others (58,59). Gujer's results indicate that the inclusion of digester supernatant recycle, to the extent that the ammonium-nitrogen concentration increases by 5 mg/L, can reduce the growth rate of *Nitrosomonas* by approximately 20 percent. The study assumed that the inhibiting compound was produced as a by-product of anaerobic degradation, versus any change in process conditions in the suspended growth reactor resulting from introduction of the digester supernatant.

### 3.3.6 Effect of Feed Organic Carbon to Nitrogen Ratio

The ratio of the feed biodegradable organic carbon, or CBOD, to the nitrogen available for nitrification in the wastewater (i.e., the C:N) is one of the critical factors affecting the design of nitrification systems. (A discussion of the C:N may also be found in Chapter 2 (Section 2.4.1.4).) Normally, for all nitrification systems, there is sufficient organic matter in the reactor feed to enable the growth of heterotrophic bacteria. Since the yield of heterotrophic bacteria is greater than the yield of the autotrophic nitrifying bacteria, there is a danger, when attempting to control the MLSS at a desired level, that the growth rate of the heterotrophic organisms will be



## Chapter 4

# Process Chemistry and Kinetics of Biological Denitrification

### 4.1 Introduction

This chapter reviews the fundamentals of the chemistry, biochemistry, and kinetics of denitrification, focusing on the treatment process. The discussion seeks to provide an understanding of the underlying principles affecting the performance, design, and operation of denitrification processes. Subsequent chapters deal specifically with the design and operation of these processes.

Biological denitrification involves the microbial reduction of nitrate to nitrite, and ultimately nitrite to nitrogen gas. Nitrate and nitrite replace oxygen for microbial respiration in this reaction; as such, denitrification is commonly thought to occur only in the absence of molecular oxygen. The conditions suitable for denitrification—oxygen is absent but nitrate is present—are commonly referred to as anoxic.

Since nitrogen gas is relatively biologically inert, denitrification converts nitrogen from a potentially objectionable form (nitrate) to a form that has no significant effect on the environment (nitrogen gas). As discussed in Chapter 1, nitrate in water can be objectionable if nutrient enrichment is a concern and/or if the water is intended to be potable. Denitrification in wastewater treatment applications may also provide process benefits in certain situations, including the development of alkalinity, the reduction of oxygen demand, and production of an activated sludge with better settling characteristics.

### 4.2 Fundamentals of Denitrification

#### 4.2.1 Microbiology

Unlike nitrification, a relatively broad range of bacteria can accomplish denitrification. Denitrifiers are ubiquitous in most natural environments, including municipal wastewaters and sludges (1,2). Many of the microorganisms in municipal activated sludge systems are denitrifiers, even in systems that are not specifically designed for denitrifying. The presence of the organisms is due in part to the fact that they are facultative: they can use either oxygen or nitrate as their terminal electron acceptor. Denitrifiers can proliferate in aerobic systems because of their ability to use oxygen and efficiently oxidize organic matter (2).

The ubiquity of denitrifiers minimizes the need to create special environmental conditions for their survival, as must be done for nitrifiers.

#### 4.2.2 Metabolism and Biochemical Pathways

In the process of denitrification, nitrate and nitrite act as electron acceptors in the respiratory electron transport chain in the same manner as oxygen. This transport chain is the fundamental mechanism by which cells generate energy. The process involves transferring electrons from a reduced electron donor (e.g., an organic substrate) to an oxidized electron acceptor (e.g., oxygen, nitrate, nitrite, or sulfate). Nitrate or nitrite may serve as a substitute for oxygen in this chain with only small modifications to the metabolic system (i.e., the enzymes) of the bacteria. By using nitrate or nitrite in place of oxygen in the electron transport chain, however, slightly less energy is generated. Similarly, more energy is generated using nitrate than sulfate.

Control systems exist within individual bacteria and natural microbial populations that ensure the most efficient form of energy generation is utilized. Thus, if oxygen is present, it will be used preferentially over nitrate, and if oxygen is not present, nitrate will be used preferentially over sulfate. Since the bacteria that reduce sulfate (sulfate reducers) cannot compete effectively with nitrate reducers for the available organic matter, sulfate reduction to sulfide and resulting odor production are not likely to occur in a treatment system that is anoxic (i.e., where nitrate is present). Also, significant sulfate reduction is not likely to occur in a system that may be void of oxygen and nitrate for short periods of time (e.g., the few hours in the anaerobic zone of a biological phosphorus removal activated sludge system), since the sulfate reducers will not have adequate time to proliferate in the numbers required to carry out significant sulfate reduction. Moreover, sulfate reducers may be poisoned in the aerobic zones of such systems.

The control mechanism in denitrifiers that allows them to switch from oxygen to nitrate occurs at two levels. The first is the synthesis of the enzymes required for denitrification. In pure cultures, oxygen has been found to repress the synthesis of these enzymes. Between 2 and

### 4.3.3 pH and Alkalinity Effects

The response of denitrification and aerobic respiration rates to pH variations should be similar. In general, denitrification will be much less sensitive to pH than nitrification. Representative observations of the effect of pH on denitrification rates are shown in Figure 4-2. These data suggest that denitrification rates are depressed below pH 6.0 and above pH 8.0. Since denitrification will produce alkalinity, it may increase the pH if high concentrations of nitrate are to be removed.

### 4.3.4 Effects of Inhibitors

Denitrifiers are much less sensitive to inhibitory compounds than are nitrifiers. In general, inhibitors would be expected to have a similar degree of impact on denitrification and heterotrophic aerobic respiration. Consequently, commonly applied concentrations that result in inhibition (e.g., those published by EPA for activated sludge and trickling filters [27]) can be used for denitrification. The ability of a biomass to acclimate to higher levels of inhibitory compounds should be taken into account when reviewing these values. Much higher concentrations may be tolerated by acclimated cultures. Specific

literature should be reviewed or pilot tests conducted to determine actual inhibitory levels.

### 4.3.5 Effect of Diffusional Limitations

Diffusional limitations will affect the design of fixed film reactors for denitrification as they will for fixed film reactors for nitrification (see Section 3.4). In general, the equations presented above are applicable to fixed film systems only if they are coupled with equations that describe diffusional limitations. Models have been developed that take such limitations into account (see Chapter 5). However, the design of many attached growth reactors is quite often based on empirical results from pilot and full-scale systems. Rates of denitrification in these empirical approaches are often based on media surface area or media volume.

For reactors that provide very turbulent conditions, such as fluidized beds, the rate of mass transport may be so high that diffusion may not limit the rate of reaction. The design of such reactors may be based on the same equations as those used for suspended growth reactors, provided the biomass in the reactor can be estimated.

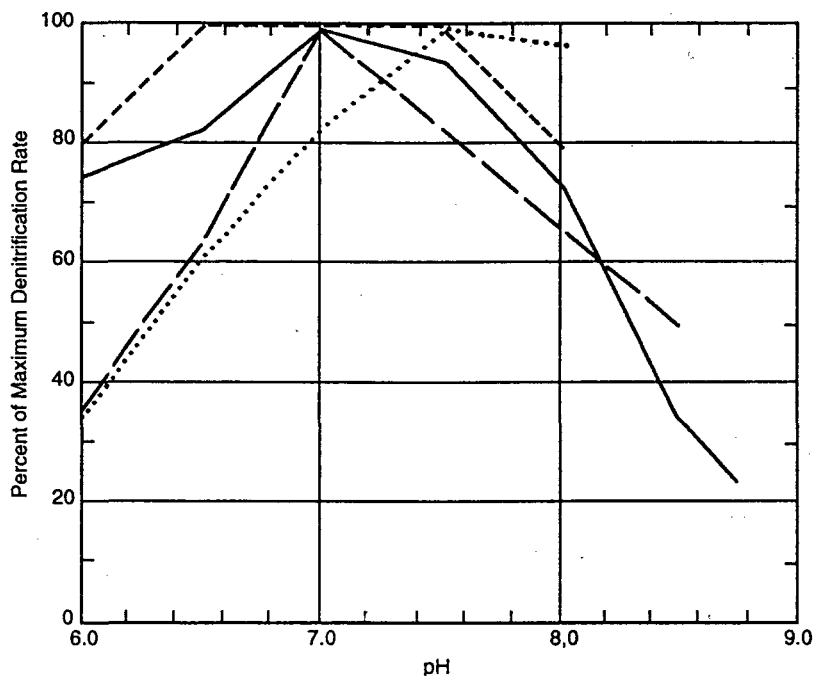


Figure 4-2. Effect of pH on denitrification rates (from Reference 11).

#### 6.4.8.1 Design and Performance Information

Each supplier of SBR system equipment has their own approach to design (see Section 8.2.6.1). Some SBR systems are custom designed and the uniqueness of each of these systems reflects the preferences of the design engineer. Designs include the use of different tank configurations, different system hydraulics and a variety of options for aeration, mixing, effluent discharge, and sludge wasting. Systems are normally configured to vary their operation automatically in response to changes in influent flow rate, or to allow the operator to initiate changes to the total cycle time or individual step times, or to make changes during each step (e.g., change length of time for aeration or mixing during fill step). The steps and associated conditions and purpose of a complete, typical cycle for a single tank operated as part of an IFID SBR system designed to achieve nitrification are described in Table 6-14. Nitrification takes place during the react phase and during the portions of the fill period when aeration is practiced.

In order to design SBRs for nitrification, an adaptation of the approach used in the design of complete mix systems is normally acceptable. The specific calculation procedure will be dictated by the characteristics of the selected SBR system. The most important calculation steps are to determine the minimum required aerobic solids residence time (using Equation 6-1 or the modified versions discussed earlier, which account for the effects of limiting DO and pH conditions), and to determine the minimum volume requirements that will assure adequate time for

settling and decanting. Other critical parameters for the design of the SBR system can be determined from information presented in Section 8.2.6.2 and elsewhere (55).

SBR systems are typically designed and operated at long solids residence times (>15 days) and low F/M (less than 0.1 kg BOD<sub>5</sub>/kg MLSS/d). Consequently, partial or complete nitrification is nearly always observed (53,55). In a recent evaluation of 19 SBR treatment plants (53) (all originally designed for nitrification), influent and effluent ammonia-nitrogen data were reported for eight of the plants (Table 6-15). The average effluent ammonium-nitrogen concentration for the eight plants was less than 2.0 mg/L, implying that a high degree of nitrification was achieved in all cases. These efficiencies reflect the long design solids residence times that are employed and operations that are generally well below the design flow.

#### 6.4.9 Powdered Activated Carbon Activated Sludge Systems

The powdered activated carbon (PAC) activated sludge system is a process modification of the activated sludge process. The addition of PAC to plug flow and complete mix suspended growth reactors is a more common process modification for industrial wastewater treatment, and has been applied to municipal systems in some instances. PAC is added to the aeration tank, where it is mixed with the biological solids (Figure 6-10). The mixed liquor solids are settled and separated from the treated effluent in a gravity clarifier. Polyelectrolyte will normally be added prior to the clarification step to enhance solids-

Table 6-14. Typical Cycle for a Single Tank in a Dual Tank SBR System Designed for Nitrification (Adapted from Reference 55)

Step	Conditions	Purpose
FILL	Influent flow into SBR Aeration occurs continually or intermittently Time = half of cycle time	Addition of raw wastewater to the SBR; COD removal and nitrification
REACT	No influent flow to SBR Aeration Time typically = 1 to 2 hours (varies widely depending on nitrification kinetics, waste strength, and amount of aeration during fill)	Carbonaceous oxidation and nitrification
SETTLE	No influent flow to SBR No aeration Time = approximately 1 hour (depends on settling characteristics)	Allow SS to settle, yielding a clear supernatant
DRAW	No influent flow to SBR No aeration Effluent is decanted Time = 1 hour (variable)	Decant—remove clarified effluent from reactor; 15 to 25 percent of the reactor volume is typically decanted, depending on hydraulic considerations and SBR manufacturer's design
IDLE	No influent flow to SBR No aeration Sludge is wasted Time = variable (determined by flow rate)	Multi-tank system, which allows time for one reactor to complete the fill step before another starts a new cycle; waste sludge—remove excess solids from reactors

Note: A typical total cycle time is 4 to 6 hours.

Table 6-15. Nitrification Performance Information for SBR Operating Plants (Adapted from Reference 53)\*

Plant Location	Period of Evaluation	Wastewater Flow		Percent of Design Flow	BOD <sub>5</sub> , mg/L		Ammonia-N, mg/L	
		m <sup>3</sup> /d	mgd		Influent	Effluent	Influent	Effluent
Buckingham, PA	04/89-04/91	439	0.116	49	324	8	25.3	1.1
Clarkston, MI (Chateau Estates)	11/89-04/91	208	0.055	50	192	12	39.1	1.7
Grundy Center, IA	12/89-11/90	2,176	0.575	72	195	4	15.8	1.2
Marlette, MI	07/90-06/91	1,578	0.417	60	103	4	10.1	0.5
Mifflinburg, PA	10/88-03/91	2,763	0.73	81	105	12	7.8	0.4
Monticello, IN (White Oaks Resort)	10/89-05/91	15	0.004	8	131	5	3.1	0.3
Muskegon Heights, MI (Clover Estates)	01/88-10/90	132	0.035	78	185	9	21.2	0.7
Windgap, PA	02/90-10/90	2,116	0.559	56	160	7	12.9	0.6

\* Average monthly values based on all data available.

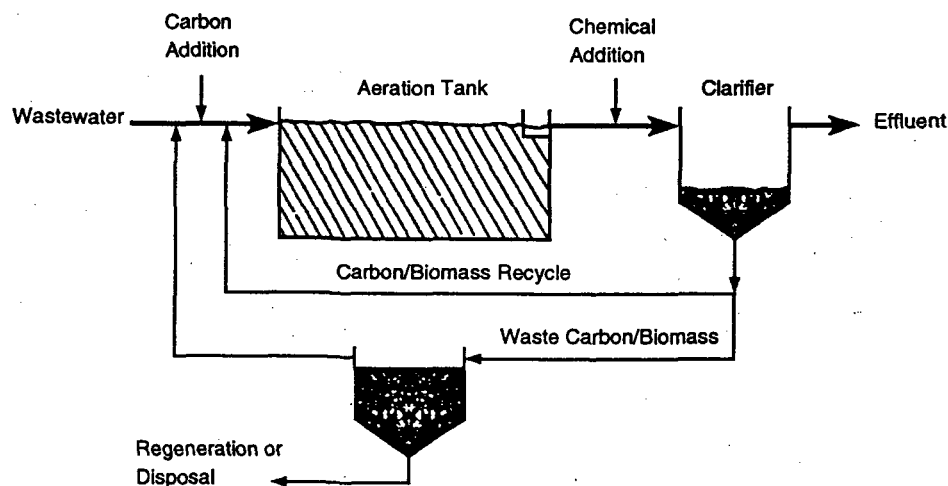


Figure 6-10. Powdered activated carbon activated sludge system.

liquid separation. If phosphorus removal is necessary, alum is often added at this point also. Even with polyelectrolyte addition, tertiary filtration is normally required to reduce the level of effluent SS. The clarifier underflow solids are continuously returned to the aeration tank. A portion of the carbon-biomass mixture is wasted periodically to maintain the desired solids inventory in the system.

Demonstrated advantages of PAC addition to suspended growth reactors include improved solids settling and dewatering characteristics; the ability of PAC to adsorb biorefractory materials and inhibitory compounds, improving effluent quality and reducing the impact of organic shock loads; reduction in odor, foaming, and sludge bulk-

ing; and improved color and CBOD<sub>5</sub> removal (49). Because PAC is wasted with excess biomass, virgin or regenerated PAC addition is required to maintain the desired concentration in the biological reactor. This can represent a significant cost factor for the system. When carbon addition requirements exceed 900 to 1,800 kg (2,400-4,000 lb)/d, wet air oxidation/regeneration (WAR) is claimed to represent an economical approach to carbon recovery and waste biomass destruction (56). However, an ash separation step is needed in this case, affecting the economics of carbon regeneration and recovery (57). The economic analysis is further clouded by the inability to analytically differentiate powdered carbon from background refractory volatile materials, thus making it difficult to quantify the value of the volatile suspended material

recovered after WAR. Although ash separation processes have been reported to be effective in at least two municipal PAC activated sludge plants (58,59), the economics of complete PAC/WAR systems relative to other activated sludge nitrification systems are unclear (57).

In the United States, PAC activated sludge systems for nitrification generally have been applied at municipal treatment plants where industrial sources contribute a significant fraction of the incoming wastewater. In all instances PAC regeneration was included in the flowsheet (60). A summary of selected municipal PAC facilities is presented in Table 6-16.

#### 6.4.9.1 Design and Performance Information

The procedure to follow in designing PAC activated sludge systems for nitrification involves a modification to those for complete mix (Section 6.4.1) or conventional plug flow systems (Section 6.4.3.1) in order to account for the effects of the addition of PAC. According to the major supplier of the technology (60), most PAC systems are designed at MLTSS concentrations of approximately 15 g/L. The mixed liquor is composed of volatile activated carbon, biomass, nonvolatile PAC ash, biomass decay components, and influent inert material. The relative proportions of these materials are strongly influenced by whether carbon regeneration via wet air oxidation and a return of this material to the aerator is practiced. The intent is to maintain the PAC concentration at approximately 1.5 times the biomass level in nitrification PAC reactors (60). The most appropriate PAC concentration will be dictated by the specific wastewater characteristics and often cannot be specified without bench or pilot scale studies. The PAC concentration to be added will depend

on the design solids retention time, the hydraulic retention time and the required PAC concentration in the reactor. The PAC concentration to be added can be calculated from:

$$PAC_o = \frac{(PAC_R)t}{\theta_c^d} + PAC_i \quad (6-24)$$

where:

$PAC_o$  = influent PAC concentration, mg/L

$PAC_R$  = mixed-liquor PAC concentration in the reactor, mg/L

$PAC_i$  = effluent PAC concentration, mg/L

$t$  = hydraulic retention time, d

The value of  $PAC_i$  in Equation 6-24 can be estimated by assuming that the carbon fraction in the effluent TSS is the same as the fraction of PAC in the MLSS.

As an example, if complete mix hydraulics were employed for the bioreactor of the PAC activated sludge system, the design procedure would follow Steps 1 through 8 as detailed in Section 6.4.2.2. In order to complete Steps 9 and 10,  $X$  needs to be selected recognizing that the total MLSS will now include PAC. Once  $X$  and  $PAC_R$  are specified and  $t$  is determined from Equation 6-15, the required influent PAC concentration can be calculated from Equation 6-24.

**PAC activated sludge nitrification systems are normally selected when the municipal wastewater contains compounds originating from industrial operations, as stated previously. Nitrifiers are susceptible to a number of organic and inorganic inhibitors found in many industrial wastewaters, as noted in Section 3.3.5 and**

Table 6-16. Summary of Municipal PAC/WAR Facilities Reviewed (57)

Facility	Current/Design Flow, m <sup>3</sup> /s	PAC/WAR <sup>a</sup> Status	Reason for PAC <sup>b</sup>	Permit Limits		
				BOD <sub>5</sub> , mg/L	TSS, mg/L	NH <sub>4</sub> -N, mg/L
Vernon, CT	0.18/28	MA	C	10	20	—
Mt. Holly, NJ	0.11/22	MA	C,S	30	30	20
E. Burlington, NC	0.31/53	MA	C,N,T	12-24	30	4.0-8.0
S. Burlington, NC	0.30/42	AS	C,N,T	12-24	30	4.0-8.0
Kalamazoo, MI	1.1/2.4	MA	C,N,T	7-30	20-30	2.0-10.0
Bedford Hts., OH	0.15/15	NAC	N,S	10	12	5.1
Medina Co., OH	0.31/44	MA	N	10	12	1.5-8.0
N. Olmsted, <sup>c</sup> OH	0.26/31	AS	N,S	30	30	2.3-6.9
Sauget, IL	0.70/1.2	AS	T	20	25	—
El Paso, TX	0.20/44	MA	N,O	SD <sup>d</sup>	SD	SD

<sup>a</sup> MA = Modified operation and/or design for ash control. AS = Converted to conventional activated sludge. NAC = Converted to the use of nonactivated carbon without regeneration.

<sup>b</sup> C = Color Removal; S = Space; N = Nitrification; T = Toxics; O = Organics.

<sup>c</sup> Plan to convert to NAC without regeneration.

in Section 6.3.1. Researchers have provided evidence that the addition of PAC to nitrifying activated sludge systems receiving industrial wastewaters improved nitrification rates (61,62). More recently, studies have been completed with the goal of determining the mechanism of nitrification enhancement in PAC activated sludge systems in the presence of adsorbable and nonadsorbable inhibitors (63). The results indicated that the addition of the proper amount of PAC can completely nullify the toxic effects of an adsorbable nitrification inhibitor. A minor positive effect on nitrification rates was observed when PAC was added to a nitrifying activated sludge system receiving nonadsorbable inhibitors. The activated sludge used in these studies was not acclimated to the inhibiting compounds.

#### 6.4.10 Other Design Considerations for Suspended Growth Nitrification Systems

##### 6.4.10.1 Selection of Peaking Factors, Safety Factors, and Process Design Factors

The selection of peaking factors and safety factors for process design should not be confused. Peaking factors are used to reflect assumed realities under the controlling conditions of the design. Safety factors are used to reflect uncertainty in performance under these realities. Whether or not the two are conceptually multiple to establish an overall process design factor depends on the application; judicious application of both peaking and safety factors can avoid a clearly inappropriate under- or over-designed condition.

The development of the design example in Chapter 2 introduces the reader to concepts associated with the development of the peaking factors for process design. They first reflect the compliance interval of the plant's effluent objectives (Section 2.9.3.1). These factors then consider the variability of the influent wastewater characteristics (Section 2.9.3.2) and their impact on the integrated works of the treatment plant (Section 2.9.3.3) for the processes under investigation (Section 2.9.3.4). The impact of the wastewater characteristics and their implied peaking factors are evaluated under the planned modes of operation through the preparation and use of mass balances (Sections 2.9.3.5 and 2.9.3.6, respectively). The developmental discussion and concluding table for the design example (Table 2-18) show that the elected processing peaks vary as a function of the unit process and processing considerations, with the layered impact of the processing recycles.

The designer can influence the process design peaking factors for the raw wastewater and processing recycles through equalization and diversion, or split-treatment strategies, and the elected processes and operating strategies for the treatment works. Longer hydraulic and solids residence times, and continuous, as opposed to

discontinuous, processing, serve to mitigate pollutant mass peaks through the treatment system.

Flow peak mitigation is one of the most important—if not the most important—concerns in suspended growth systems because of solids washout concerns. Here, the designer should consider the applicability of automatic high flow diversions around the reactor and/or the entire biological treatment system, as well as flow equalization with the equalization tank dedicated to receiving both the first and the end-of-storm sewer flushing events. Other peaking factor considerations, beyond these general considerations, are best considered as a function of the reactor design.

Safety factors in process design are ultimately expressions of design confidence. They are used when there is uncertainty. Higher safety factors may be used where the technology is less demonstrated or more unproven. One example of a commonly used safety factor in design is multiplication by two of the reciprocal of the controlling design *Nitrosomonas* specific growth rate ( $\mu_N$ ). This solids residence time is expected to accommodate unknown variations in temperature, DO, residual ammonium concentration, operating variations, and pH (if determined to be applicable). Conceptually, the sound design approach would be then to apply this solids residence time under the controlling design conditions that are established by correct application of the peaking factors.

##### 6.4.10.2 Incorporation of Phosphorus Removal

Chapter 2 provides the stoichiometry of the phosphorus removal reactions (Table 2-3), and the considerations associated with the incorporation of phosphorus removal with a suspended growth nitrification system are largely developed in Section 2.7.2 and demonstrated in Design Example No. 1 (Section 6.4.2.2). A summation of the salient points as they may influence suspended growth nitrification systems follows:

- Solids Production:
  - All designs must anticipate the production of additional waste solids due to the phosphorus removal step and select a design MLSS concentration with this in mind.
  - Stringent levels of phosphorus removal may not be obtainable with secondary equivalency levels of effluent SS (e.g., maximum 30-day average of 30 mg/L) because of the increasing phosphorus concentrations in the sludge mass and effluent SS.
- Metal Salt Addition Strategies:
  - Must anticipate the attendant alkalinity depletions if an acid carrier is used with the metal salts.
  - May be especially attractive in multipoint addition strategies for improved solids-liquid separation (with or without polymers), and with upstream primary



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from Hillsborough County (Appendix B) shows complete nitrification at chloride levels of 2 to 2.5 g/l.

Methanol is not adsorbed by activated carbon to any significant extent as noted in two separate studies (Appendix D). Further, since bacteria reside on the carbon particles, it would be likely that methanol adsorbed on the carbon would be available to those bacteria.

Attached are BOD, COD and TOC data from the plant at El Paso. It shows no "bleed through" of the above constituents due to methanol addition.

Also attached are data from the Hillsborough County, FL plant for COD. Unfortunately, TOC and BOD are not available. This plant not only has elevated levels of TDS, but it contains a very high fraction of refractory COD. The reader will notice that nitrogen removal is not impeded by the levels of COD reported in the effluent. This COD is NOT a measure of un-used methanol. Any excess methanol is removed in a re-aeration step prior to final clarification. This re-aeration step is in place at both the El Paso plant and the Hillsborough plant.

Also enclosed as promised by John Meidl is a chronology of events report as assembled by Zimpro.

If we can be of any further assistance, do not hesitate to contact me.

Best regards,

A handwritten signature in cursive script that reads 'David Beula'.

David Beula  
Project Manager

cc: MRM  
KTD  
JAM

## CITRUS COUNTY PACT® SYSTEM

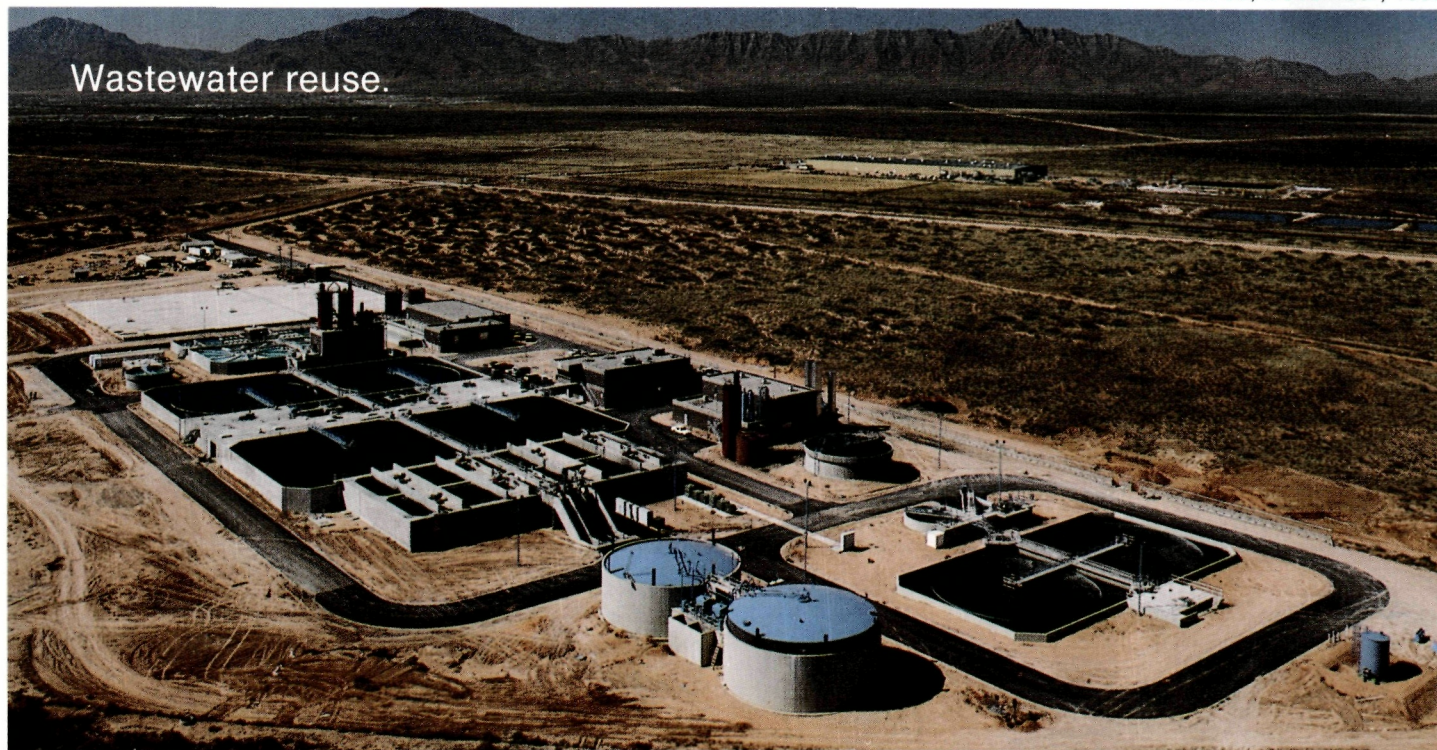
### CHRONOLOGY OF EVENTS: ZIMPRO ENVIRONMENTAL INC.

February 1993	County notifies Zimpro of the appearance of nitrates in the plant effluent
March 16, 1993	Data evaluation notes influent leachate characteristics significantly different than design. Zimpro meets with County and Engineer on-site. Several trips by Zimpro's representative, E. K. Phelps & Co., were also made to the site during mid '93 to early '94.
April	Zimpro technician travels to site to install new PLC program (2 visits)
May	Zimpro technician travels to site to modify PLC program (bumping of reactors)
March - May	County expands sampling for leachate and effluent to obtain data per Zimpro recommendation
June - July	Zimpro obtains samples and conducts study to determine plant loading and treatment effectiveness. County personnel directed to obtain samples. Zimpro paid for shipping and analysis, and provided report/recommendations to test supplemental carboneous source.
September	Report submitted to County by Zimpro on June - July sampling recommending comprehensive testing and analysis.
November 15	Citrus County gives go ahead to Zimpro to do further testing on-site (Zimpro personnel not available until January 1994)
February 1-11, 1994	Zimpro on-site to perform testing with molasses as supplemental carboneous source
March 21	Report on denitrification/mixing submitted to Citrus County
August	Cost sharing agreement between Citrus County Zimpro and PBS & J signed to modify PACT system to two-stage design



**APPENDIX A**





## El Paso closes the loop.

Leon Metz remembers the first time he came to El Paso, TX, and went down to see the Rio Grande River.

"I expected to find it wide and flowing," recalls the El Paso historian and river expert. "Instead, I found a trickle of water that I could almost jump across."

That scarcity of fresh water in the El Paso area has led to construction of the state-of-the-art treatment plant that converts raw sewage to high quality effluent that meets drinking water standards and is pumped back into the aquifer. The plant was commissioned last June; Metz was the keynote speaker.

Designed by the El Paso firm of Parkhill, Smith and Cooper, Inc., and built by the M.A. Mortenson Co. of Minneapolis, MN, the new facility can treat up to 10 million gallons a day (current average flow is about half that). Wastewater passes through ten separate treatment steps—including a two-stage PACT™ system licensed by Zimpro Inc. of Rothschild, WI.

The treated water is returned to the Hueco Bolson aquifer through a system of 10 recharge wells, each reaching down some 800 feet. Over a period of two years, it will migrate back to the potable water wellheads.

*Above, Fred Hervey Treatment Plant surrounded by arid land. Center, crystal clear effluent is returned to aquifer. Right, aerator of PACT™ system.*

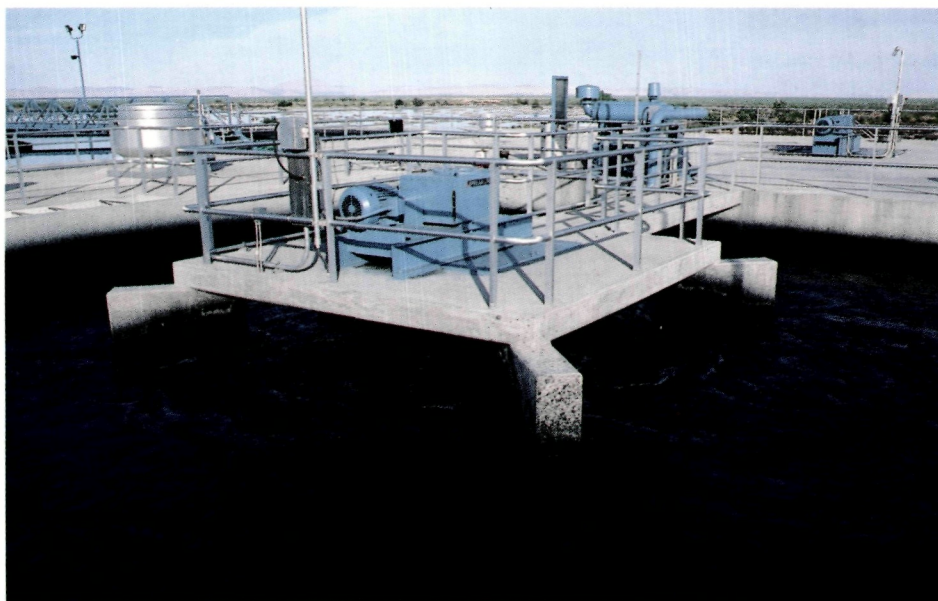


### Steps to save water.

The plant is named for Fred Hervey, who founded the El Paso Public Service Board and championed water resources 30 years ago. It is just one of a number of steps this arid area of the Southwestern United States has taken to guarantee a constant supply of fresh water in the years ahead.

According to John Hickerson, general manager of the Public Service Board, these efforts include an aggressive water conservation

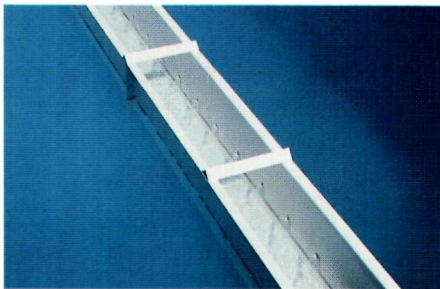
*(continued)*







Above, two-stage PACT™ system clarifiers loom in foreground. Carbon regeneration unit is at upper left. Below, effluent from PACT system goes to lime treatment and looks "swimming pool" clear.



## El Paso, cont.

program, acquisition of private land over the Hueco Bolson, leasing of surface water rights to the Rio Grande, and attempts to obtain rights to groundwater deposited beneath Federal lands near El Paso in New Mexico.

"Our objective is to employ a combination of methods to assure El Paso of an adequate supply of water over the next 100 years, even though our population may reach 2 million," he says.

The Fred Hervey plant will help meet that goal by returning water to the Hueco Bolson—source of about 65 percent of El Paso's fresh water, but being depleted about 20 times faster than the natural recharge rate.

### Purification processes.

Wastewater begins the road to recovery by entering the plant from a collection system that serves about 50,000 residents in the northeast part of El Paso, near Fort Bliss. Primary treatment includes screens, degritting, and settling basins. Primary sludge is anaerobically digested and dewatered on drying beds before being composted. Digester gas is used for plant fuel.

After flow equalization, the purification process continues as primary effluent enters the two-stage PACT system, which accomplishes the bulk of the organic removal, including all of the nitrogen removal.

Large amounts of powdered

activated carbon are carried in the PACT system aeration basins, allowing physical adsorption and biological treatment to occur simultaneously. The carbon adsorbs what the biomass can't handle; the biomass assimilates pollutants that aren't adsorbed.

Aided by the PACT system's long SRT (solids residence time), nitrification occurs in the first stage; denitrification in the second, Methanol—in smaller amounts than those required by conventional systems—is added to the second stage to provide carbon for the denitrifiers, assuring nitrogen levels of less than five parts per million.

After aeration, the treated wastewater moves on to secondary clarifiers. The waste sludge and spent carbon are withdrawn and pumped to a wet air regeneration unit—supplied by Zimpro. Here, at temperatures of 450 degrees F and pressures of 950 pounds per square inch, the organic material is wet oxidized. The carbon is regenerated for return to the PACT system.

Clarifier overflow advances to high lime treatment for virus kill, removal of phosphorus and heavy metals, and softening.

Sand filtration is next for turbidity removal, followed by ozonation for disinfection and granular activated carbon.

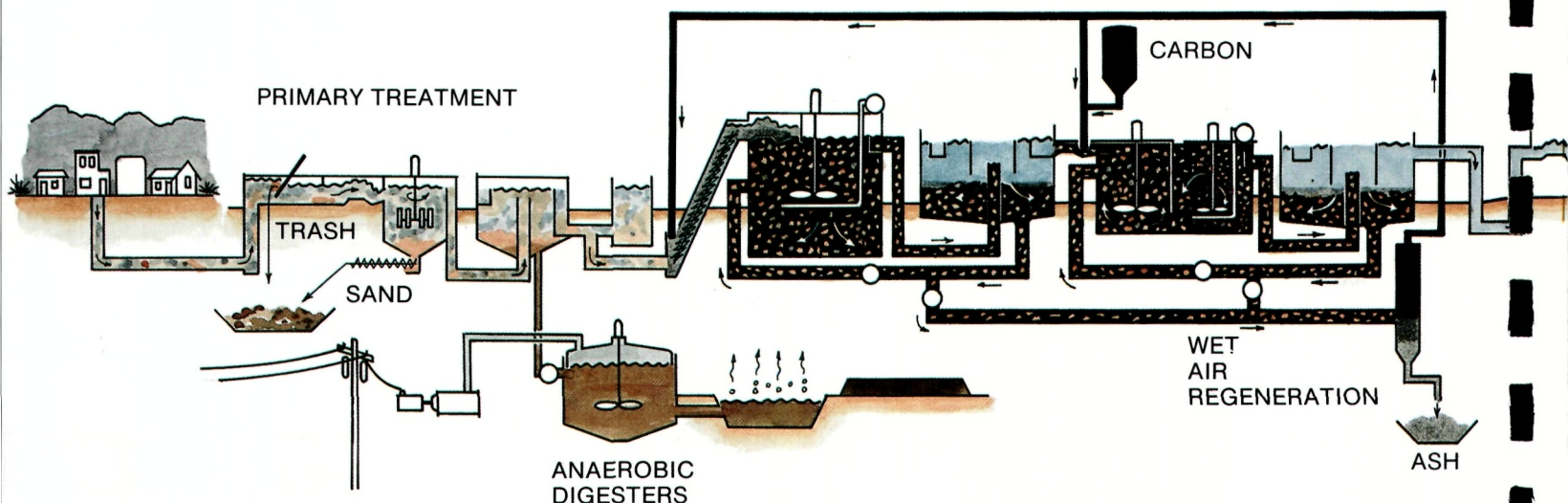
The product water is stored and tested for purity in one of the most

### PACT system performance El Paso, TX

	In (mg/l)	Out (mg/l)
BOD	—	less than 3
TOC	—	less than 2
COD	180	less than 10
TKN	25	less than 1
NO <sub>3</sub>	less than 1	less than 5
TN	25	less than 5
SS	56	less than 5

## FRED HERVEY WATER RECLAMATION PLANT

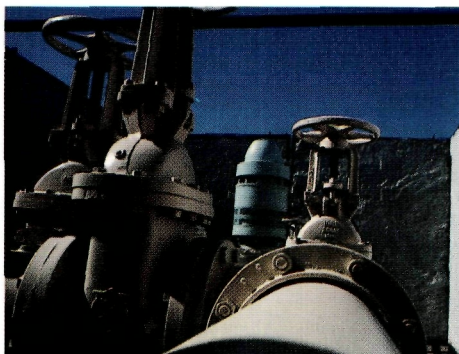
### PACT™ SYSTEM







Plant effluent is pumped to well-field (above) near the treatment plant, and recharged to aquifer through ten 800-foot wells (below).



sophisticated laboratories in the wastewater industry. Some 23 parameters are measured, including alkalinity, heavy metals, and trihalomethanes, before the water is released to the recharge wells.

#### Performance report.

The PACT system, and the treatment plant as a whole, have been performing well since startup (see chart).

"We selected this system for its reliability and capacity to handle toxic shocks and other extraordinary loads without upset," says Dan Knorr, project manager with Parkhill, Smith and Cooper.

#### Data:

**Plant:** Wastewater reclamation, recharge.

**Flow:** 10 million gallons per day (0.4 m<sup>3</sup>/s).

**Zimpro processes:** 2-stage PACT system; wet air regeneration unit (capacity 60 gallons per minute or 3.8 L/s; operating conditions 450°F, or 230°C, at 950 psig, or 66 kgf/cm<sup>2</sup>).

**Other processes:** Primary, equalization, sludge digestion, high lime, 2-stage recarbonation, sand filtration, ozonation, GAC filtration.

**Recharge:** 10 wells, 800 feet (243 m) deep.

**Designer:** Parkhill, Smith and Cooper, Inc., El Paso, TX.

**General contractor:** M.A. Mortenson Co., Minneapolis, MN.

**Owner:** El Paso Public Service Board, John Hickerson, general manager; Robert Bustamante, assistant general manager.

**Plant superintendent:** Javier Hernandez.

"To date, the product water has met or exceeded expectations."

The effluent is impressive.

At the open house in June, members of the public sampled it on the rocks or mixed with fruit punch, and gave it high marks.

One visitor confirmed the wisdom of reuse and even suggested the El Paso project was a model for others to follow.

"It makes good sense," he told the El Paso Times, "With population increasing all over the Southwest, we're going to need this. More people have been killed over water than over women."

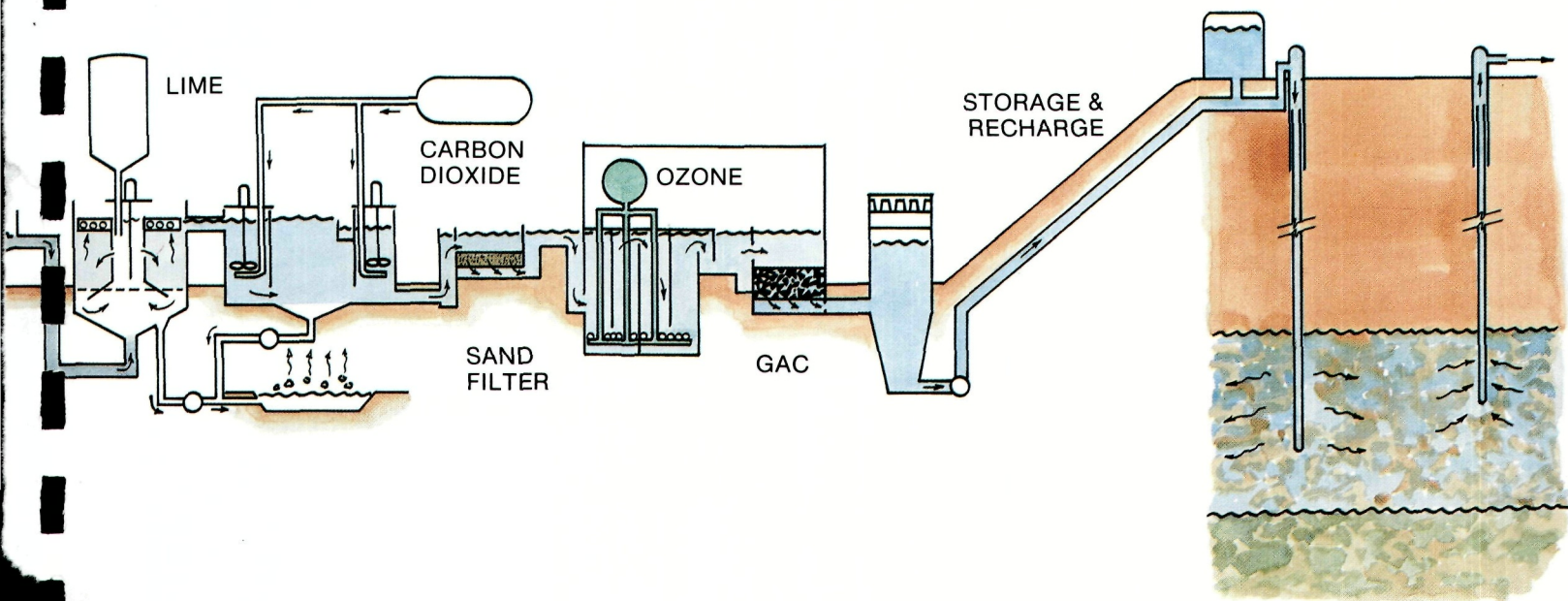


To landscape the new treatment works, El Paso uses and identifies trees and bushes that require little water.

#### Discharge Parameters El Paso, TX (established by Texas Water Commission)

Chlorides	300 mg/l
Sulfates	300 mg/l
Nitrates as N	10 mg/l
Turbidity	1 NTU
Arsenic	0.05 mg/l
Barium	1.0 mg/l
Cadmium	0.010 mg/l
Hexavalent Chromium	0.05 mg/l
Copper	1.0 mg/l
Iron	0.3 mg/l
Lead	0.05 mg/l
Manganese	0.05 mg/l
Mercury	0.002 mg/l
Selenium	0.01 mg/l
Silver	0.05 mg/l
Zinc	5.0 mg/l
Total dissolved solids	1000 mg/l
Endrin	0.0002* mg/l
Lindane	0.004* mg/l
Methoxychlor	0.1* mg/l
Toxaphene	0.005* mg/l
Chlorophenoxys	
2,4-D	0.1* mg/l
2,4,5-TP Silvex	0.01* mg/l

\*annual average



EL PASO, TX

## MONTHLY DATA REPORT

FLAGGED RESULTS

REPORTING PERIOD:

FROM: AUGUST 01, 1994

D213

TO: AUGUST 31, 1994

D243

PARAMETER	RAW	PRIM CLAR	CON AER	1st CLAR	2nd CLAR
BOD	159	142	162	4	2
COD	181	155	137		
TOC	52.6	48.4	44.4	4.08	2.94
TKN	31.9	29.9	30.1	1.6	1.1
AMMONIA	19.4	18.8	19.3		
SUS SOLIDS	282.8	115.8	245.0	11.5	7.5
VOL SOLIDS	186.9	76.4	138.0	8.1	6.4
TDS					653
TURBIDITY	116				
ALKALINITY	256				170
HARDNESS	180				162
CL2 RES					
EC					1083
DILUTED EC					
CHLORIDES					183
FLUORIDES					0.92
SULFATES					76.6
BROMIDES					0.28
NITRATES					3.18
ortho PHOSPHATES	3.5				2.79
total PHOSPHORUS	3.3				2.88
SILICA					34
CYANIDES					
pH	7.3	7.3	7.5	7.3	7.9
@ (TEMPERATURE)	18.1	15.0	17.9	17.2	17.1
SODIUM	155				160
POTASSIUM	17.4				17.5
SODIUM	44.0				45.6
POTASSIUM	12.78				12.57

COMMENTS:



EL PASO, TX

# MONTHLY DATA REPORT

FLAGGED RESULTS

REPORTING PERIOD:

FROM: SEPTEMBER 01, 1994 D244

TO: September 30, 1994 D273

PARAMETER	RAW	PRIM CLAR	CON AER	1st CLAR	2nd CLAR
BOD	160	141	135	2	
COD	135	143	88		
TOC	48.2	58.5	34.5	3.81	3.04
TKN	30.9	29.0	36.1	1.2	0.9
AMMONIA	18.9	19.4	23.6		
SUS SOLIDS	151.3	80.5	435.3	7.9	4.6
VOL SOLIDS	131	66	257	5	3
TDS					630
TURBIDITY	99				
ALKALINITY	260				171.4
HARDNESS	174.7				159.2
CL2 RES					
EC					1067.0
DILUTED EC					
CHLORIDES					182
FLUORIDES					1
SULFATES					71.79
BROMIDES					0.3
NITRATES					2.33
ortho PHOSPHATES					2.87
total PHOSPHORUS	3.45				2.85
SILICA					38
CYANIDES					
pH	7	7	7	7	8
@(TEMPERATURE)	14	14	17	16	16
SODIUM	140.6				154.0
POTASSIUM	13.68				17.07
CALCIUM	48				43
MAGNESIUM	11.7				13.9

COMMENTS:

# MONTHLY DATA REPORT

FLAGGED RESULTS

REPORTING PERIOD:

FROM: 100191

D274

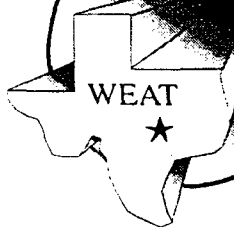
TO: 103191

D304

PARAMETER	RAW	PRIM CLAR	CON AER	1st CLAR	2nd CLAR
BOD	171	129	123	5	2
COD	212	186	133	40	23
TOC	56.5	50.8	40.9	5.57	4.54
TKN	31.2	29.2	37.1	3.4	2.5
AMMONIA	19.8	19.6	24.6	1.6	
SUS SOLIDS	173.3	86.3	348.4	10.0	7.8
VOL SOLIDS	136.5	61.6	220.0	6.9	6.5
TDS					672
TURBIDITY	98				
ALKALINITY	259				171
HARDNESS	171				167
CL2 RES					
EC					1144
DILUTED EC					
CHLORIDES					196
FLUORIDES					0.85
SULFATES					84.5
BROMIDES					0.27
NITRATES					2.19
ortho PHOSPHATES					2.83
total PHOSPHORUS	3.6				3.12
SILICA					35
CYANIDES					
pH	7.2	7.3	7.6	7.2	7.8
@ (TEMPERATURE)	13.9	13.5	16.8	16.5	16.5
SODIUM	160				166
POTASSIUM	15.7				16.3
SODIUM	43.8				45.8
POTASSIUM	11.87				11.19

COMMENTS:

# PIPELINE

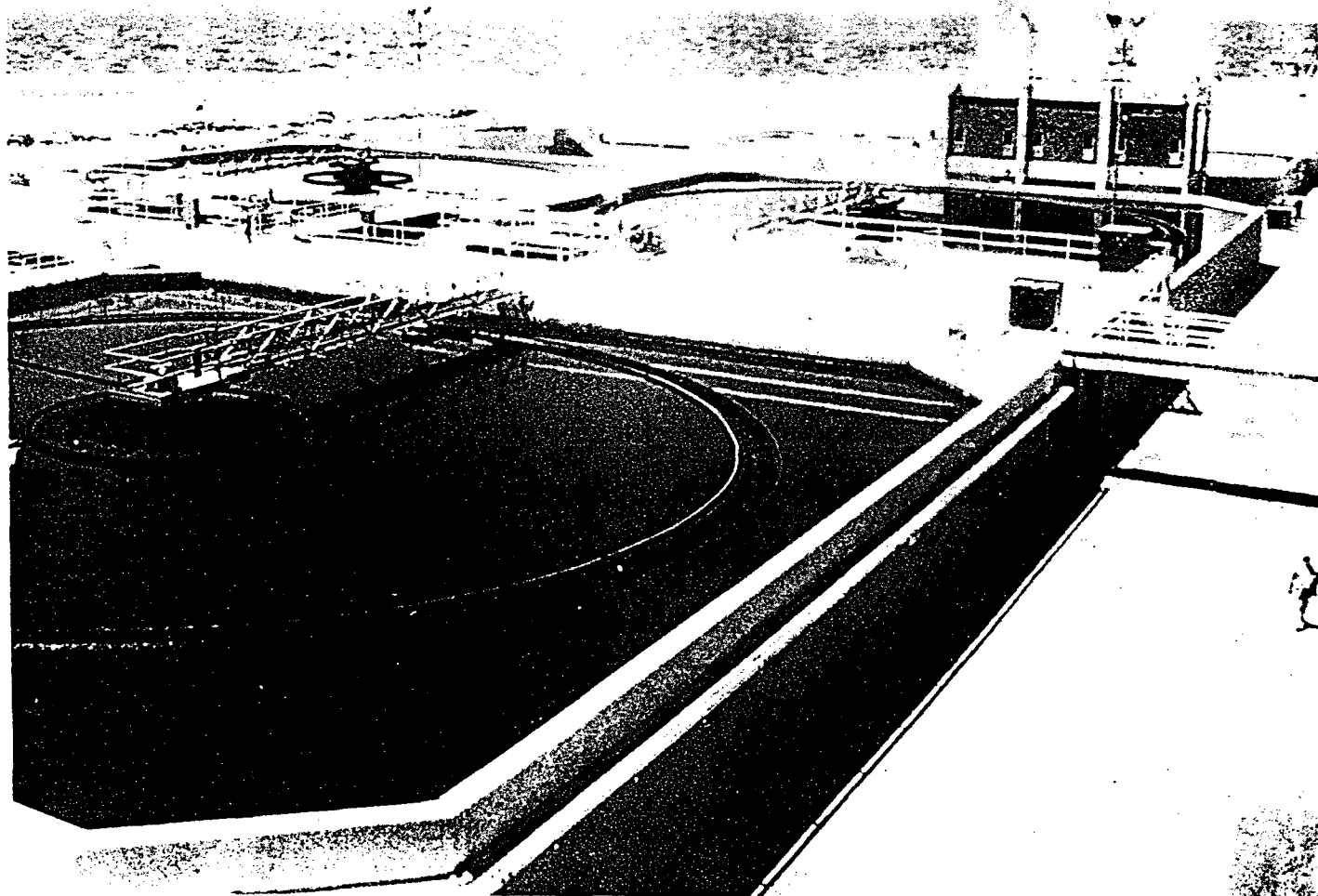


An Official Publication of the  
Water Environment Association of Texas



VOLUME 11 ISSUE 6

NOVEMBER, 1994



The El Paso Water Utilities' Fred Harvey Water Reclamation Plant that artificially recharges the Hueco Bolson Aquifer has proven to be a successful venture(see related article inside).



# AN UPDATE ON ARTIFICIAL GROUNDWATER RECHARGE IN EL PASO, TEXAS

by Robert G. Boyd of Parkhill, Smith & Cooper, Inc.

The concept of artificial groundwater recharge in El Paso was embraced in the 1970's, predominantly in response to studies performed by the United States Geological Survey (USGS), which showed that the primary source of drinking water for El Paso, the Hueco Bolson Aquifer, was being depleted at rates which could exhaust the 10 million acre-feet of fresh water contained therein by early in the 21st century.

The current recharge project which began full-scale operation in 1985, includes the El Paso Water Utilities Fred Hervey Water Reclamation Plant with a capacity of 10 million gallons per day (MGD), a pipeline system, and 10 injection wells. All the wastewater treated at the Fred Hervey Water Reclamation Plant (FHWRP) is collected in the northeast area of El Paso. The wastewater is transported to the FHWRP and treated to meet U.S. Environmental Protection Agency (USEPA) drinking water standards. Portions of the FHWRP effluent are currently reused for industrial purposes and as irrigation water for a golf course. The remaining effluent is injected directly into the Hueco Bolson Aquifer.

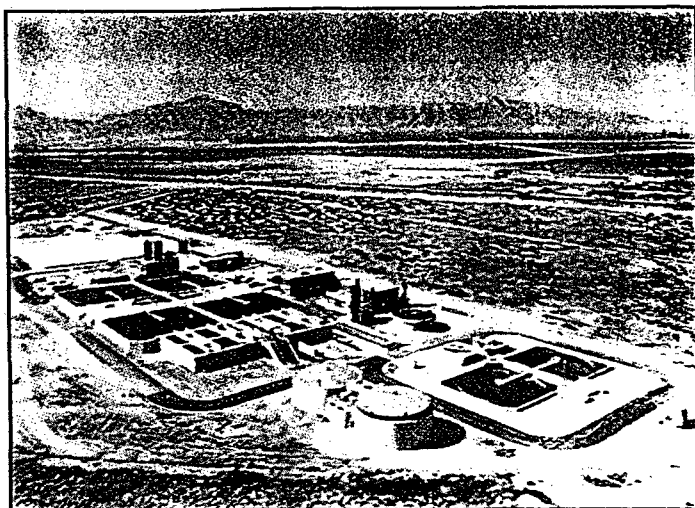
The process units utilized at the FHWRP include screening, degritting, primary clarification, flow equalization, two-stage PACT® treatment, lime treatment, two stage recarbonization, sand filtration, ozonation, granular activated carbon filtration, chlorination, and storage. Two parallel 5 MGD treatment trains make up the 10 MGD system.

The two stage bio-physical PACT® process is the backbone of the treatment process. This process combines a conventional aerated biological treatment system with the use of powdered activated carbon (PAC). This process provides the majority of the removal of organics and all of the nitrogen compound removal.

The fail-safe features of the FHWRP process trains provide a very strong element of reliability. The FHWRP was designed to provide redundant means of pollutant removals. For example, the high lime treatment will remove pathogens, as does each of the sand filtration, ozonation, and chlorination processes. In addition to these redundancies, the wastewater can be bypassed to equalization ponds for treatment from any point in the process. The success of the fail-safe features has been demonstrated in the reliable production of high quality water, which even meets the USEPA secondary drinking water standards for aesthetics.

Plant removal efficiencies indicate the performance of the treatment processes have been within 10% of the design values for the conventional parameters: biochemical oxygen demand, chemical oxygen demand, total sus-

pended solids, ammonia nitrogen, total Kjeldahl nitrogen, phosphorous, and total nitrogen.



The FHWRP has validated its design by operating eight years without a discharge permit violation. The plant has met or exceeded the design parameters consistently since start-up. The unit cost for treatment has been reduced substantially from \$3.14/1000 gallons to \$1.35/1000 gallons since the initial year of operation.

The effluent from the FHWRP not used for industry or irrigation is conveyed via pipeline to ten injection wells. The injection wells are located within an area of the Hueco Bolson which will provide much of the water supply for the El Paso area. The injection wells are located approximately three-fourths of a mile up-gradient and one-fourth of a mile down-gradient from the existing El Paso Water Utility production wells in the area. The locations of the injection wells were selected to provide a projected minimum 2-year residence time for injected water prior to withdrawal by production wells.

By the end of 1991, it had been determined that over 28,000 acre-feet of reclaimed water had been injected into the Hueco Bolson Aquifer. Flow model analyses have indicated that recharge has offset the regional decline in water levels that otherwise would have occurred over an area of 20 square miles. The maximum benefits exceed a one foot per year reduction in the decline of the water level within that area. Based upon the flow model analyses, the projected water level benefits of the recharge project are much greater than those which have occurred historically. By the year 2005, maximum benefits should reach 26 feet in some areas, and benefits over four feet should extend five miles north and south of the injection

field. Two feet or more of water-level benefits will have been realized over an area of more than 175 square miles.

Additionally, a solute transport model indicates that as of 1990, the maximum movement of any injected solute was 3,200 feet down-gradient, and 1,800 feet up-gradient from the injection wells. Within this area maximum concentrations of a stable solute were indicated to be 70% of that being injected.

In summary, the recharge project has provided the following:

- 1) the effect of the recharge project on groundwater quality has shown no substantial detrimental effect;
- 2) the effectiveness of the FHWRP in terms of pollutant removal has been demonstrated;
- 3) the reliability of the FHWRP to produce potable water in a cost effective manner has been demonstrated, and;
- 4) The recharge project has advanced the state-of-the-art in wastewater reclamation design and artificial groundwater recharge.

This project has also met with broad and continuing public acceptance. This acceptance is vital to ensure the continued success of this project and any other project of this type.

In the face of constantly dwindling sources of potable water in areas such as the El Paso region, wastewater reclamation and reuse will become more of a necessity than a novelty. This ongoing project in El Paso serves as an example of the ability to provide a safe, economical and renewable source of potable water in such situations.

## TEXAS WATER DEVELOPMENT BOARD

### Statewide EPA Drinking Water Needs Survey Begins in November

Under the direction of the U.S. Environmental Protection Agency (EPA), the Texas Water Development Board (TWDB) and the Texas Natural Resource Conservation Commission (TNRCC) are jointly conducting a drinking water survey to estimate short- and long-term capital investment needs of water utility systems in Texas. Water systems to be surveyed will be notified on or before November 1, 1994. TWDB and TNRCC staff involvement in the survey will include visits with as many survey recipients as possible to provide assistance with completing the survey.

The importance of participating in this survey cannot be overemphasized as the results will be reported to Congress and will be used to determine Texas' share of federally appropriated funds. Currently, Congress is considering reauthorization of the federal Safe Drinking Water Act that would include the creation and funding of a state-administered drinking water revolving loan program similar to the State projects. The drinking water SRF would provide low-interest loans to local governments for water utility system improvements.

This year, Congress has appropriated, but not yet authorized, \$600 million for a drinking water SRF. An appropriation of \$700 million has been suggested for 1995, and future funding of up to \$1 billion each year from 1996 to 2000 is possible. Texas' share of these funds will be influenced directly by the results of surveys being conducted nationwide by the EPA.

Out of approximately 4500 community water systems in Texas, about 300 will be surveyed. From this survey, drinking water facility needs for the entire state are to be estimated for all projects anticipated to occur within the next 20 years. Needs may include obtaining new water sources; expansion or improvements to treatment, storage, transmission, and distribution facilities; and costs to consolidate nearby water systems and/or nearby residences with inadequate water supplies.

Information about the survey is available by contacting Bill Allen, Texas Water Development Board, P. O. Box 13231, Austin, Texas 78711; 512-463-8430.

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\* PATENTS PENDING

### 1994-95 WEAT ACTIVITIES CALENDAR

Date	Event	Contact	Phone
Nov 1-3	West Texas Reg School (Lubbock)	Henry Day	806/767-3227
Dec 7	Pipeline Deadline	Bill Coloby	713/640-7013
Dec 9	Teleconference Bd Mtg	Stephen Jenkins	512/353-4444
May 23-25, 1995	WEAT Annual Con. (Fort Worth)	Dan Allen	512/453-6574
Sep 10-13, 1995	WEF Collection System Specialty Conf	John D'Antoni (Houston)	713/676-3409

**APPENDIX B**

HILLSBOROUGH COUNTY FLORIDA  
PACT SYSTEM

INFLUENT DATA

DATE	LAB	SAMPLE	RAW LEACHATE		PH FIELD	PH LAB	TSS MG/L	TKN MG/L	NH3-N MG/L	NO3-N MG/L	COD MG/L
			FLOW GPD								
11-16-94	PBS&J	1	60,890		7.35	7.57	25	217		1.76	925
11-16-94	PBS&J	2			7.32	7.52	36	228		0.86	1425
11-16-94	ESCAN	1			7.35	7.55	26	269	259	2.19	797 M
11-16-94	ESCAN	2			7.32	7.46	30	264	256	1.32	827 M
12-07-94	PBS&J	1	62,341								
12-07-94	PBS&J	2									
12-07-94	ESCAN	1			7.31	7.66	30		282	6.08	580 M
12-07-94	ESCAN	2			7.22	7.54	24		295	4.84	684 M

EFFLUENT DATA  
SECOND (DENITRIFICATION) STAGE CLARIFIER

DATE	LAB	SAMPLE	PH FIELD	PH LAB	TSS MG/L	TKN MG/L	NH3-N MG/L	NO3-N MG/L	COD MG/L
11-16-94	PBS&J	1	8.30	8.44	20	5.00		0.02	485
11-16-94	PBS&J	2	8.35	8.49	21	5.39		0.04	500
11-16-94	ESCAN	1	8.30	8.44	25	5.50	1.0	<0.5	339 M
11-16-94	ESCAN	2	8.35	8.41	25	5.78	0.2	<0.5	322 M
12-07-94	PBS&J	1							
12-07-94	PBS&J	2							
12-07-94	ESCAN	1	8.22	8.41	34		<0.08	<0.5	320 M
12-07-94	ESCAN	2	8.24	8.42	14		<0.08	<0.5	294 M

FLORIDA DER REQUIREMENTS      6.2-8.5      60/30/20      ----      ----      12      ----

M = EPA METHOD 410.1 (MACRO COD)

**APPENDIX C**

PERFORMANCE TEST REPORT  
FOR THE PACT<sup>®</sup> LEACHATE TREATMENT SYSTEM  
PLANT LOCATION: BFI REDBIRD LANDFILL  
ARNOLD, MISSOURI  
OWNER: BROWNING-FERRIS INDUSTRIES  
ZIMPRO ENVIRONMENTAL, INC.  
PROJECT NO.: 21-2647/30.1

PACT<sup>®</sup> is a registered trademark of  
Zimpro Environmental, Inc.

July 23, 1993

KID:mn

  
**ENVIRONMENTAL, INC.**  
An Affiliate of the Black Clawson Co.  
301 W. Military Road, Rothschild, WI 54474  
Telephone (715) 359-7211 • FAX (715) 355-3219

## TABLE OF CONTENTS

	<u>PAGE</u>
1.0 Introduction . . . . .	1
2.0 Summary of Results . . . . .	2
Table 2.0 Conventional Pollutants (mg/L) . . . . .	2
Table 2.1 Metals (ug/L) . . . . .	4
Table 2.2 Organics (ug/L) . . . . .	4
2.3 Discussion . . . . .	4
3.0 Carbon Dosage . . . . .	8
4.0 Test Procedure . . . . .	8
5.0 Operating Parameters . . . . .	8
Table 5.1 Operating Parameters . . . . .	9
Appendix A	
Performance Test Procedure	
Appendix B	
Analytical Data	
Appendix C	
Test Coordinator's Report	

## 1.0 INTRODUCTION

Performance testing of the PACT<sup>R</sup> leachate treatment system at the BFI Redbird Landfill (BFI; OWNER) was conducted from 0001 hours on June 20, 1993 to 2400 hours on June 24, 1993.

The purpose of the test was to demonstrate compliance with performance specifications of effluent quality under controlled test conditions.

The test results contained in Section 2.0, Summary of Results, indicate that the PACT system successfully complied with the performance requirements for effluent characteristics as specified in Section IX, Performance Guarantee of the Equipment Purchase Agreement; Exhibit B, Proposal for a PACT Leachate Treatment System Prepared for BFI Redbird Landfill; dated March 31, 1992, revision dated April 29, 1992. The PACT system, in meeting the performance test specifications, should now be considered as accepted by Browning-Ferris Industries.

This report summarizes the results of the testing and provides all necessary supporting documentation and data.



## 2.0 SUMMARY OF RESULTS

Table 2.0 Conventional Pollutants (mg/L)

<u>Influent</u>				<u>Effluent</u>		
<u>Date</u>	<u>Total COD</u>	<u>Design (Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>	<u>Reduction %</u>
		1,843		< 600		
6/20/93			657		295	
6/21/93			874		382	
6/22/93			710		321	
6/23/93			473		376	
6/24/93			439		354	
			Mean 631		346	45.2
<u>Date</u>	<u>Total BOD</u>	<u>Design (Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>	<u>%</u>
		406		< 300		
6/20/93			77		7	
6/21/93			185		13	
6/22/93			124		6	
6/23/93			56		7	
6/24/93			31		9	
			Mean 95		8	91.6
<u>Date</u>	<u>T. Susp. Solids</u>	<u>Design (Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>	<u>%</u>
		62		< 50		
6/20/93			133		50	
6/21/93			95		70	
6/22/93			90		40	
6/23/93			116		57	
6/24/93			89		89	
			Mean 105		61	41.9

X = Analyzed but not detected.

<u>Influent</u>				<u>Effluent</u>		
<u>Date</u>	<u>Ammonia Nitrogen</u>	<u>Design (Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>	<u>Reduction %</u>
		313		N/A	0.2	
6/20/93			305		0.3	
6/21/93			369		0.7	
6/22/93			320		0.4	
6/23/93			354		0.5	
6/24/93			<u>251</u>		<u>0.3</u>	
			Mean 320		0.4	99.9

<u>Date</u>	<u>Ortho Phosphorus</u>	<u>Design (Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>	<u>%</u>
		N/A		N/A		
6/20/93					1.4	
6/21/93					1.8	
6/22/93					1.7	
6/23/93					1.5	
6/24/93					<u>1.3</u>	
					1.5	

<u>Date</u>	<u>pH</u>	<u>Design Range (SIU)</u>	<u>Test Results (SIU)</u>	<u>Design Range (SIU)</u>	<u>Test Results (SIU)</u>
		6.5-8.0		5.5 - 11.5	
6/20/93			7.3		7.6
6/21/93			7.3		7.3
6/22/93			7.3		7.6
6/23/93			7.2		7.9
6/24/93			<u>7.2</u>		<u>7.9</u>
		Range 7.2 - 7.3		Range 7.3 - 7.9	

#### Hydraulic and COD Mass Loading

<u>Date</u>	<u>Design</u>	<u>Flow MGD</u>	<u>COD mg/L</u>	<u>COD lbs./day*</u>
	0.035 MGD			
6/20/93		0.035873	657	197
6/21/93		0.028464	874	207
6/22/93		0.019558	710	116
6/23/93		0.037133	473	147
6/24/93		<u>0.028216</u>	<u>439</u>	<u>103</u>
	Mean	0.029849	631	154

\* COD lbs/d = Flow, MGD x 8.34 lb/gal x COD, mg/L

Table 2.1 Metals (mg/L)

	<u>Influent</u>		<u>Effluent</u>	
	<u>Design</u> <u>(Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>
Antimony	0.047	0.007	0.5	0.006
Arsenic	0.039	0.002	0.3	0.001
Barium	1.71	0.946	10.0	0.485
Beryllium	0.005	x	0.1	x
Cadmium	0.005	x	0.4	x
Chromium	0.049	x	5.0	0.010
Copper	0.010	x	1.5	x
Cyanide, Amenable	0.006	0.011	0.1	x
Iron	43.2	23.5	25	1.99
Lead	0.056	0.004	0.2	x
Mercury	0.0004	x	0.01	x
Nickel	0.34	.114	1.0	0.130
Selenium	0.005	x	0.2	x
Silver	0.005	x	0.01	x
Zinc	3.26	0.249	3.0	0.085

Table 2.2 Organics (mg/L)

	<u>Influent</u>		<u>Effluent</u>	
	<u>Design</u> <u>(Max.)</u>	<u>Test Results</u>	<u>Design</u>	<u>Test Results</u>
Phenolic Compounds	1.42	0.0024J	0.05	x
Oil & Grease	150	2.81	200	x

X = Analyzed but not detected

J = Estimate

### 2.3 Discussion

A 5-day (120 hour) performance test of the PACT<sup>®</sup> leachate treatment system was conducted from 0001 hours on June 20, 1993 to 2400 hours on June 24, 1993. The performance requirements for the PACT influent and PACT effluent respectively, are shown in the summary of results (Table 2.0, 2.1 and 2.2) under the column heading "Design".

**APPENDIX D**

A DYNAMIC MODEL OF NITRIFICATION-  
DENITRIFICATION IN THE ACTIVATED SLUDGE SYSTEM  
WITH POWDERED ACTIVATED CARBON

A THESIS  
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL  
OF THE UNIVERSITY OF MINNESOTA

BY  
JONG SOULL LEE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF  
DOCTOR OF PHILOSOPHY

DECEMBER, 1977.

## ABSTRACT

The requirement of high levels of wastewater treatment often demands complete removal of nitrogen, and the use of suspended growth biological nitrification-denitrification systems are accepted methods for satisfying this requirement. Also, it has been shown that the addition of powdered activated carbon (PAC) to the activated-sludge system enhances the stability of operation and increases substrate removal.

The objective of this research was to combine PAC with suspended growth biological reactors and study the systems for nitrification and denitrification by developing a dynamic model of the system and verifying it with pilot plant data obtained under dynamic flow conditions.

For the PAC model, batch tests were conducted to obtain basic information on adsorption of various substrates and dissolved oxygen (DO), PAC-cell growth, solids settling and kinetic coefficients. Scanning electron microscopic (SEM) examinations were conducted with and without PAC at 20°C.

To obtain dynamic data, two two-sludge nitrification-denitrification activated-sludge pilot plants were operated in parallel with dynamic loading, one of which had PAC in the mixed liquor. Data were obtained using sampling periods of 24 to 56 hours and 2-hour sampling intervals. The degree of nitrification-denitrification was dependent upon hydraulic detention time as well as solids retention time, and this was shown by the results of the dynamic test data. Cyclic patterns of effluent nitrate concentrations were obtained from both the nitrification and denitrification processes similar to the cyclic flow and loading rates imposed on the processes, although the former lagged the latter by 2 to 4 hours. Nitrification effluent dissolved organic carbon (DOC) concentrations did not follow the sharp contrast of dynamic loading because as loading decreased non-biodegradable DOC's were increased. The denitrification effluent did not contain significant amounts of DOC.

Analytical solutions of the dynamic model were obtained from computer programming using Newton-Shooting iteration with Modified Euler integration. Model predictions were obtained for each nitrification and denitrification test through computer analysis, and very good agreement was obtained between the predictions

(i) Organic Substrate. . . . .	101
(j) Adsorption Equation. . . . .	102
5. Summary of Equations . . . . .	102
 (D) Denitrification Model. . . . .	104
1. Assumptions. . . . .	104
2. Monod Expressions with Modifying Equations . . . . .	104
(a) Monod Expression for Specific Growth Rate . . . . .	104
(b) Modified Arrhenius Expressions for Temperature Corrections. . . . .	104
3. Balance Equations Around the Reactor . . . . .	105
(a) Total Nitrogen . . . . .	105
(b) Organic Nitrogen . . . . .	105
(c) Ammonia Nitrogen . . . . .	107
(d) Nitrate Nitrogen . . . . .	107
(e) Denitrifiers . . . . .	109
(f) Organic Substrate. . . . .	109
(g) Adsorption Equation. . . . .	110
4. Summary of Equations . . . . .	111
5. Notations for Nitrification-Denitrification . . . . .	113
 (E) Computer Programming . . . . .	116
1. Review of Analytical Methods for the System . . . . .	116
2. Programming Step . . . . .	119
 IV. BATCH TYPE EXPERIMENTS AND RESULTS . . . . .	122
 (A) PAC Adsorption Experiments . . . . .	122
1. General. . . . .	122
(a) Characteristics of PAC Hydrodarco H. . . . .	122
(b) pH of the PAC, Titration Curve and Alkalinity . . . . .	125
(c) PAC Recovery Test. . . . .	130
2. Adsorption Tests . . . . .	131
(a) General. . . . .	131
(b) Glucose and Glutamic Acid. . . . .	134
(c) Lactose. . . . .	137
→ (d) Methanol . . . . .	138
(e) Nitrogen . . . . .	139
(f) Dry Milk Solution. . . . .	140
(g) Seneca Primary Effluent. . . . .	146
(h) Isotherm Tests on Dry Milk Solution. . . . .	148
(i) Dissolved Oxygen . . . . .	154



described in part (a) were followed for the remainder of the test. It was difficult to obtain the same TOC concentrations from replicate samples, and therefore each test result was obtained from an average of 10 analyses of each sample. As the results show, substantial reductions in the concentrations occurred during the prolonged time periods. This reduction cannot be attributed entirely to adsorption since methanol is highly volatile, as mentioned previously. Volatilization during mixing in the beaker (regardless of the aluminum foil cover), while sampling and filtering the sample, and during exposure while running the TOC analyses was considered the main reason for the continuing reduction. Whether the methanol reacted with any functional groups or inorganic substances on the surface of the carbon is not known.

The amount of methanol adsorbed as calculated from the test data was 13 to 17% of the initial concentration in a 1 g/l PAC solution. However, considering the loss due to volatilization, the amount adsorbed should be somewhat less.

(e) Nitrogen

$\text{NH}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  were tested for adsorption and the results are recorded as Test V. All of these

IMAGE QUALITY

AS YOU VIEW THE FOLLOWING  
DOCUMENT, PLEASE NOTE THAT  
PORTIONS OF THE ORIGINAL WERE OF  
POOR QUALITY

# Activated carbon adsorption of petrochemicals

D. M. GIUSTI, R. A. CONWAY, AND C. T. LAWSON

AS STREAM QUALITY CRITERIA have become increasingly stringent, several advanced methods have been considered for more efficient treatment of wastewater. Removal of residual organic compounds from wastewater by activated carbon adsorption is the advanced method that has received the most attention.<sup>1</sup>

Carbon treatment can be applied in a typical flow scheme for a facility treating petrochemical plant wastes at two positions. A tertiary treatment stage for removing refractory organics following conventional secondary (biological) treatment usually is visualized. However, because of the high concentration of impurities encountered in various individual waste streams contributing to the total discharge, some of the streams might be treated more effectively at their sources rather than at the terminal facility. This latter approach could be beneficial particularly in handling process unit wastes that produce shock loads to a treatment plant, produce materials that inhibit biological activity, or produce economically recoverable materials.

The phenomenon of activated carbon adsorption in dilute aqueous systems has been studied diligently only in the past few years. Most of the extensive work in physical-chemical treatment up to this time has been with municipal wastewater systems where the concentration of the impurity is often one to two orders of magnitude less than that to be considered with commonly encountered petrochemical wastes. The size and functionality of the organic substances involved are also markedly different between municipal and petrochemical wastes. Work to date with petrochemical waste streams has been to test actual effluents to obtain data for sizing treatment facilities.

Only a very limited amount of the literature refers to adsorptive capacities of various carbons for specific compounds. Manufacturers' specifications for their carbons provide only sketchy information relating to the effects of functionality, molecular weight, pH, branching, solubility, polarity, and carbon surface chemistry. A compilation of data evaluating these parameters for a group of test carbons and pure compounds should be useful in predicting results for treatment of specific or combined wastes. The project described in this paper was undertaken as a step toward fulfilling this technological gap.

## LITERATURE SURVEY

Morris and Weber<sup>2,3</sup> have reported a considerable amount of data on the adsorption of phenol, sodium salts of sulfonated organics, and pesticides. Increasing molecular weight was shown to have a favorable effect on carbon capacity, while branching had an adverse effect. Also, total carbon removal for a mixture was enhanced compared with that expected from single-solute data. Ward and Getzen<sup>4</sup> showed that decreasing the pH increased the adsorption of aromatic acids not only because of an increase in the molecular-ionic ratio but also because of an enhanced specific ion adsorption resulting from an alteration of the carbon surface properties. In their Freundlich isotherm studies of the relationship between adsorption of phenolics and surface chemistry, Snoeyink *et al.*<sup>5</sup> found that phenol was adsorbed more extensively by a coal-base carbon than by a coconut-shell carbon. Aly and Faust<sup>6</sup> reported carbon loading values as high as 0.3 g/g of carbon at a residual concentration of 1 mg/l for the adsorption of the herbicide 2,4-dichlorophenoxyacetic acid

TABLE I.—Amenability of typical organic compounds to activated carbon adsorption

Compound	Molecular Weight	Aqueous Solubility (%)	Concentration (mg/l)		Adsorbability*	
			Initial (C <sub>i</sub> )	Final (C <sub>f</sub> )	g compound/g carbon	Percent Reduction
Alcohols						
Methanol	32.0	∞	1,000	964	0.007	3.6
Ethanol	46.1	∞	1,000	901	0.020	10.0
Propanol	60.1	∞	1,000	811	0.038	18.9
Butanol	74.1	7.7	1,000	466	0.107	53.4
n-Amyl alcohol	88.2	1.7	1,000	282	0.155	71.8
n-Hexanol	102.2	0.58	1,000	45	0.191	95.5
Isopropanol	60.1	∞	1,000	874	0.025	12.6
Allyl alcohol	58.1	∞	1,010	789	0.024	21.9
Isobutanol	74.1	8.5	1,000	581	0.084	41.9
t-Butanol	74.1	∞	1,000	705	0.059	29.5
2-Ethyl butanol	102.2	0.43	1,000	145	0.170	85.5
2-Ethyl hexanol	130.2	0.07	700	10	0.138	98.5
Aldehydes						
Formaldehyde	30.0	∞	1,000	908	0.018	9.2
Acetaldehyde	44.1	∞	1,000	881	0.022	11.9
Propionaldehyde	58.1	22	1,000	723	0.057	27.7
Butyraldehyde	72.1	7.1	1,000	472	0.106	52.8
Acrolein	56.1	20.6	1,000	694	0.061	30.6
Crotonaldehyde	70.1	15.5	1,000	544	0.092	45.6
Benzaldehyde	106.1	0.33	1,000	60	0.188	94.0
Paraldehyde	132.2	10.5	1,000	261	0.148	73.9
Amines						
Di-N-Propylamine	101.2	∞	1,000	198	0.174	80.2
Butylamine	73.1	∞	1,000	480	0.103	52.0
Di-N-Butylamine	129.3	∞	1,000	130	0.174	87.0
Allylamine	57.1	∞	1,000	686	0.063	31.4
Ethylenediamine	60.1	∞	1,000	893	0.021	10.7
Diethylenetriamine	103.2	∞	1,000	706	0.062	29.4
Monethanolamine	61.1	∞	1,012	939	0.015	7.2
Diethanolamine	105.1	95.4	996	722	0.057	27.5
Triethanolamine	149.1	∞	1,000	670	0.067	33.0
Monoisopropanolamine	75.1	∞	1,000	800	0.040	20.0
Diisopropanolamine	133.2	87	1,000	543	0.091	45.7
Pyridines & Morpholines						
Pyridine	79.1	∞	1,000	527	0.095	47.3
2-Methyl 5-Ethyl pyridine	121.2	sl. sol.	1,000	107	0.179	89.3
N-Methyl morpholine	101.2	∞	1,000	575	0.085	42.5
N-Ethyl morpholine	115.2	∞	1,000	467	0.107	53.3
Aromatics						
Benzene	78.1	0.07	416	21	0.080	95.0
Toluene	92.1	0.047	317	66	0.050	79.2
Ethyl benzene	106.2	0.02	115	18	0.019	84.3
Phenol	94	6.7	1,000	194	0.161	80.6
Hydroquinone	110.1	6.0	1,000	167	0.167	83.3
Aniline	93.1	3.4	1,000	251	0.150	74.9
Styrene	104.2	0.03	180	18	0.028	88.8
Nitrobenzene	123.1	0.19	1,023	44	0.196	95.6
Esters						
Methyl acetate	74.1	31.9	1,030	760	0.054	26.2
Ethyl acetate	88.1	8.7	1,000	495	0.100	50.5

TABLE I—(Continued)

Compound	Molecular Weight	Aqueous Solubility (%)	Concentration (mg/l)		Adsorbability*	
			Initial (C <sub>i</sub> )	Final (C <sub>f</sub> )	g compound/g carbon	Percent Reduction
Esters						
Propyl acetate	102.1	2	1,000	248	0.149	75.2
Butyl acetate	116.2	0.68	1,000	154	0.169	84.6
Primary amyl acetate	130.2	0.2	985	119	0.175	88.0
Isopropyl acetate	102.1	2.9	1,000	319	0.137	68.1
Isobutyl acetate	116.2	0.63	1,000	180	0.164	82.0
Vinyl acetate	86.1	2.8	1,000	357	0.129	64.3
Ethylene glycol monoethyl ether acetate	132.2	22.9	1,000	342	0.132	65.8
Ethyl acrylate	100.1	2.0	1,015	226	0.157	77.7
Butyl acrylate	128.2	0.2	1,000	43	0.193	95.9
Ethers						
Isopropyl ether	102.2	1.2	1,023	203	0.162	80.0
Butyl ether	130.2	0.03	197	nil	0.039	100.0
Dichloroisopropyl ether	171.1	0.17	1,008	nil	0.200	100.0
Glycols & Glycol Ethers						
Ethylene glycol	62.1	∞	1,000	932	0.0136	6.8
Diethylene glycol	106.1	∞	1,000	738	0.053	26.2
Triethylene glycol	150.2	∞	1,000	477	0.105	52.3
Tetraethylene glycol	194.2	∞	1,000	419	0.116	58.1
Propylene glycol	76.1	∞	1,000	884	0.024	11.6
Dipropylene glycol	134.2	∞	1,000	835	0.033	16.5
Hexylene glycol	118.2	∞	1,000	386	0.122	61.4
Glycols & Glycol Ethers						
Ethylene glycol monomethyl ether	76.1	∞	1,024	886	0.028	13.5
Ethylene glycol monoethyl ether	90.1	∞	1,022	705	0.063	31.0
Ethylene glycol monobutyl ether	118.2	∞	1,000	441	0.112	55.9
Ethylene glycol monohexyl ether	146.2	0.99	975	126	0.170	87.1
Diethylene glycol monoethyl ether	134.2	∞	1,010	570	0.087	43.6
Diethylene glycol monobutyl ether	162.2	∞	1,000	173	0.166	82.7
Ethoxytriglycol	178.2	∞	1,000	303	0.139	69.7
Halogenated						
Ethylene dichloride	99.0	0.81	1,000	189	0.163	81.1
Propylene dichloride	113.0	0.30	1,000	71	0.183	92.9
Ketones						
Acetone	58.1	∞	1,000	782	0.043	21.8
Methyl ethyl ketone	72.1	26.8	1,000	532	0.094	46.8
Methyl propyl ketone	86.1	4.3	1,000	305	0.139	69.5
Methyl butyl ketone	100.2	v. sl. sol.	988	191	0.159	80.7
Methyl isobutyl ketone	100.2	1.9	1,000	152	0.169	84.8
Methyl isoamyl ketone	114.2	0.54	986	146	0.169	85.2
Diisobutyl ketone	142.2	0.05	300	nil	0.060	100.0
Cyclohexanone	98.2	2.5	1,000	332	0.134	66.8
Acetophenone	120.1	0.55	1,000	28	0.194	97.2
Isophorone	138.2	1.2	1,000	34	0.193	96.6

Compound

## Organic Acids

Formic acid  
Acetic acid  
Propionic acid  
Butyric acid  
Valeric acid  
Caproic acid  
Acrylic acid  
Benzoic acid

## Oxides

Propylene oxide  
Styrene oxide

\* Dosage: 5 g

—325 mesh in use. Solubility concentration for some of the

Samples were analyzed according to a method and a toc analysis based on unagitated of theoretical each compound percent conversion necessary.

TABLE

Carbon*	Surf. (%)
A	
B	1.05
C	
D	1.00

\* Carbon A: sorb 400 (12 > Carbon D: Na  
† Data on surface  
‡ I—Strongly group, IV—Ca  
§ Pretreatment grinding to —

TABLE I—(Continued)

Adsorbability*		Compound	Molecular Weight	Aqueous Solubility (%)	Concentration (mg/l)		Adsorbability*	
Compound/ Carbon	Percent Reduction				Initial (C <sub>i</sub> )	Final (C <sub>f</sub> )	g compound/ g carbon	Percent Reduction
Organic Acids								
0.149	75.2	Formic acid	46.0	∞	1,000	765	0.047	23.5
0.169	84.6	Acetic acid	60.1	∞	1,000	760	0.048	24.0
0.175	88.0	Propionic acid	74.1	∞	1,000	674	0.065	32.6
0.137	68.1	Butyric acid	88.1	∞	1,000	405	0.119	59.5
0.164	82.0	Valeric acid	102.1	2.4	1,000	203	0.159	79.7
0.129	64.3	Caproic acid	116.2	1.1	1,000	30	0.194	97.0
		Acrylic acid	72.1	∞	1,000	355	0.129	64.5
		Benzoic acid	122.1	0.29	1,000	89	0.183	91.1
Oxides								
		Propylene oxide	58.1	40.5	1,000	739	0.052	26.1
		Styrene oxide	120.2	0.3	1,000	47	0.190	95.3

\* Dosage: 5 g Carbon C/l of solution.

—325 mesh in a Waring blender before use. Solubility limits dictated stock solution concentrations of less than 1,000 mg/l for some of the compounds studied.

Samples were analyzed using the cop analysis according to "Standard Methods"<sup>31</sup> and a roc analyzer. Removals of test compounds in carbon treated samples were based on untreated control samples that were agitated simultaneously. Calculations of theoretical cop and roc were made for each compound; corrections for analytical percent conversions were made where necessary.

With volatile, very low solubility compounds such as benzene, toluene, and other aromatics, losses as high as 30 percent in the control samples were measured because of the dissolved compounds coming into equilibrium with the air space above the surface of the liquid in the sealed flasks. Upon unstoppering the flasks, that portion of the compound in the vapor phase was lost to the atmosphere. This loss did not occur in the carbon treated samples because, as the carbon adsorbs the component from solution, the equilibrium shifts continuously, and the losses by vaporization

TABLE II.—Surface areas and surface acidities of stock and pretreated activated carbons

Carbon*	Surface Area† (sq m/g)	Surface Groups‡ (me/g)							
		Stock Activated Carbons				Pretreated Activated Carbons§			
		I	II	III	IV	I	II	III	IV
A	1,050	0.30	0.00	0.05	0.20	0.55	0.00	0.00	0.00
B	1,050–1,200	0.30	0.00	0.15	0.10	0.30	0.15	0.15	0.00
C	1,100	0.35	0.00	0.10	0.15	0.30	0.15	0.15	0.15
D	1,000–1,100	0.75	0.15	0.70	0.45	0.95	0.25	0.65	0.45

\* Carbon A: Witco Grade 517 (12 × 30 mesh, petroleum hydrocarbon based), Carbon B: Calgon Filtrasorb 400 (12 × 40 mesh, coal based), Carbon C: Westvaco Nuchar WV-G (12 × 40 mesh, coal based), Carbon D: Nacar G107 (12 × 30 mesh, coal based).

† Data on surface areas were provided in vendor literature.<sup>32–34</sup>

‡ I—Strongly acidic carboxyl group, II—More weakly acidic carboxyl group, III—Phenolic hydroxyl group, IV—Carbonyl group; as me acid/g carbon, by volumetric analysis.

§ Pretreatment of carbons included soaking in distilled water for 24 hr, drying at 103°C for 24 hr, and grinding to —325 mesh.