SIEMENS

Technical Report No. 077

An Overview of PACT® Wastewater Treatment for the Petroleum and Petrochemical Industries

By:

John A. Meidl, PACT® Product Manager,
Zimpro Passavant Environmental Systems, Inc.

Presented at:

Symposium - Environmental Successes in the Chemical Industry, 203rd American Chemical Society Meeting, San Francisco, CA, April 6, 1992

Siemens Water Technologies Corp.
301 West Military Road
Rothschild, WI 54474
Tel: (715) 359-7211
Fax: (715) 355-3219

I. INTRODUCTION

PACT® wastewater treatment systems have been used as a means of producing high quality effluents from both industrial and municipal wastewater for a number of years. The technology is well proven in a wide variety of applications worldwide. PACT offers a number of important advantages to industries in terms of stable high quality treatment at an economical cost. Probably the most important factor is that when utilizing PACT, the inherent stability of the process can allow it to respond to upstream upset conditions. Because of this, the refinery or other operating facility will be protected to a much greater extent from out of compliance discharge when difficulties with an upstream process or accidental spills to the sewer occur. In other words, PACT allows a facility such as a refinery to be in the business of refining petroleum without the continual worry of wastewater treatment system upsets.

Reasons for considering PACT are:

* Proven experience in treating difficult wastes
* Performance (better than biological + GAC)
  - organics
  - nitrogen
  - metals
* Stability
* Improved nitrification
* Improved bioassays (remove toxicity)
* Reduced VOC stripping
* Reduced sludge to disposal
* Lower overall costs
* Operational flexibility

II. PROCESS DESCRIPTION

The basic flow scheme of a PACT system is illustrated in the simplified flow schematic shown in **Figure 1**.

The flow scheme is virtually identical to that of a conventional activated sludge system. The basic unit processes consist of an aeration basin and clarifier. The difference is that the aeration basin contains powdered activated carbon in addition to the microorganisms used in conventional treatment. The presence of the powdered activated carbon in a PACT system greatly enhances the quality of treatment that can be achieved because now, two mechanisms for treatment exist: 1)biological assimilation and oxidation; and 2) carbon adsorption. The combination of these two mechanisms operating simultaneously offers a means of producing tertiary quality water in a single unit process. A synergism exists between the biomass and the carbon that cannot exist when those two entities are separated.

Essentially, the wastewater enters the aeration basin where it is aerated in contact with the carbon/microorganism mixture (solids). The wastewater and solids (mixed liquor) exit the aeration basin and enter the clarifier where the solids are settled and returned to the aeration basin while the treated wastewater is discharged.

A portion of the settled mixed liquor solids from the clarifier underflow is removed from the system as a sludge. This sludge can easily be dewatered to a dryness in excess of 50 percent solids without using costly polymers or other dewatering chemicals. In larger systems such as might exist in a refinery, Wet Air Regeneration (WAR) can be used to regenerate the activated carbon in the waste sludge while destroying the associated sorbed organics and biological fraction, thereby reducing the waste sludge for disposal by over 90 percent. This, too, is a key advantage in that not only can carbon costs be reduced, the ever increasing problem of sludge disposal can be minimized.

The following paragraphs will offer a more detailed discussion of some of the key elements and advantages of the PACT® technology.

III. EXPERIENCE

Zimpro Passavant Environmental Systems, Inc. has over 15 years experience in treating wastewaters with the PACT system. Some major users of the PACT system are DuPont, General Electric, Ciba-Geigy, Koch Refining, Unocal, and others. PACT systems range in size from batch treatment systems to large custom designed systems, flows ranging from less than 3,000 gpd (U.S.) to over 50 MGD (U.S.). Some of the users are listed in **Table 1**.

IV. PERFORMANCE

The PACT system is highly effective for removing priority pollutants, ammonia nitrogen, and toxicity. It is also able to remove some level of heavy metals not normally accomplished by conventional treatment systems. Removal of priority pollutants in all organic chemical plant discharges has been mandated by the U.S. Environmental Protection Agency. PACT is able to easily meet these mandated standards, as shown in **Table 2**.

Furthermore, treatment of refinery wastewater has shown that PACT can produce an effluent that will easily meet the refinery's discharge standards for contaminants as well as bioassays. Data from a refinery is shown in **Table 3**.

Removal of metals is also improved when PACT is compared to conventional biological treatment. An organic chemical plant which upgraded its existing activated sludge system shows the improvement in metals capture afforded by PACT (see **Table 4**).

V. STABILITY

In an increasingly stringent regulatory environment, industry is faced with some difficult compliance challenges. When choosing a wastewater treatment technology, not only is it important that discharge criteria such as COD, BOD, etc. be achievable under normal conditions, but more importantly under abnormal conditions.

In industries such as the petroleum refining and petrochemical industries, a facility will typically consist of many unit processes which produce wastewaters. Most of the time, these unit processes run smoothly and produce a wastewater of consistent quality. However, abnormal operations, such as during an emergency shutdown or in the event of the failure of some piece of equipment, can produce a dramatic change in the characteristics of a wastewater entering the treatment system. There are also accidental spills to the sewer which can have a devastating effect on a conventional activated sludge system. In fact, problems can occur which can completely kill off the microorganism population in a conventional activated sludge system, rendering the system completely ineffective. Under these conditions, a worst case may be that part or all of the refinery be shut down for an extended period of time.

PACT® systems offer outstanding stability. With the presence of activated carbon in the aeration system, the mechanism of carbon adsorption exists to remove what are known as shock loads, protecting the biology in the system from upstream upsets and toxic spills to the sewer. Tertiary treatment schemes such as activated carbon columns following a conventional activated sludge system cannot offer this protection since there is no carbon in the aeration system to protect the biology. Also, with powdered carbon present, solids remain in the system even under upset conditions because of carbon's "weighting" affect on the sludge. **Figure 2** demonstrates the superior settleability of PACT vs activated sludge.

VI. EFFLUENT QUALITY & BIOASSAY

Effluent quality in terms of BOD, COD, NH_3, etc., are generally spelled out in a typical discharge permit. More and more, requirements include the criteria of bioassay which looks at toxicity of the effluent to living organisms. One of the most stringent bioassay requirements in the United States is in place as a requirement for discharging industrial effluent into San Francisco Bay.

Much investigation in the petroleum industry has determined that the activated sludge process can provide a means of meeting most of the general discharge requirements. However, activated carbon is required to meet the Bio-Assay requirements: a 96 hour LC50 test using rainbow trout minnows. Rainbow trout are a very delicate species which thrive in fresh water mountain streams. The requirement for testing effluents into San Francisco Bay was that rainbow trout minnows had to survive for a minimum of 96 hours in undiluted refinery effluent. Needless to say, using such a delicate species made

the task of producing a suitable effluent extremely difficult. PACT is meeting this challenge and is providing industry discharging into the bay a reliable means of meeting all requirements. As an example, the Unocal refinery in Rodeo (near San Francisco) which has been successfully operating a PACT® system for all of their refinery wastewaters for over 2 years. The Unocal system includes Wet Air Regeneration which also solved a difficult sludge disposal problem.

Bio-assay data from another refinery was previously shown in **Table 3**. **Table 5** shows comparison of treatment of an organic chemical plant waste by an activated sludge system prior to it being upgraded to PACT, and a parallel operated pilot PACT system. The advantage shown here is that the carbon dosage can be adjusted to control effluent quality. The plant has upgraded to PACT and has achieved LC50 >100 percent over the last 3 years at a carbon dose of 350 mg/l.

When considering ammonia removal, PACT has proven to be far more efficient than conventional biological systems as shown in the date on **Table 6**. PACT is also far more dependable, even at much shorter aeration times and at reduced temperatures (see **Table 7**).

VII. REDUCED VOC EMISSIONS AND/OR ODDS

Odors from industrial plants often create serious public relations problems. It is important to consider the ability of treatment to not only produce an odorless product, but also to limit release of odors to the atmosphere where they can be a public nuisance. In a conventional activated sludge system, there is a propensity to air strip volatile organic carbon compounds (VOC). In many areas, there are regulations covering VOC emissions from treatment plants; but also, this stripping can produce odors which cause complaints from the surrounding neighborhood.

PACT virtually eliminates stripping of VOCs. The presence of powdered activated carbon in the aeration basin provides a way to hold these compounds in the wastewater treatment system where they can be destroyed rather than be stripped to the atmosphere where they can produce air quality violations and public complaint.

Treatment of a highly volatile wastewater (described in **Table 8**) showed that removal efficiencies for priority pollutants exceeded 99.9 percent while limiting air stripping out of the aeration basins to less than 1 percent of influent VOCs. This is not the case with conventional activated sludge as shown by the comparison in **Table 9** entitled "**Fate of Toxic Organics.**"

VIII. REDUCING SLUDGE DISPOSAL

Sludge disposal from a treatment plant is often one of the most difficult aspects of wastewater treatment. The problem is that when dewatering conventional activated sludge, it is usually impossible to remove the water content below 85 percent. Thus, incinerating sludge from most industrial wastewater treatment plants not only causes the usual problems associated with air emissions from an incinerator, but also the high fuel costs because of the extremely high water content of the sludge. In general, incineration can be very costly. PACT® system sludges, however, will reflect far less cake moisture (40-50 percent water) without any dewatering aids. This low moisture cake will generally contain a BTU content of 8-10,000 BTU/lb dry weight solids.

Another common sludge disposal method has been landfilling of dewatered sludge cake. Not only have landfilling costs been going up at a rapid rate, industry executives are becoming more and more aware of the liabilities their companies are being exposed to from contaminating groundwater near landfills, and the continuing problem of odors which can easily be produced by wet biological sludges. Overall, there are very serious political and economic costs associated with landfilling. PACT system sludge produces a very stable, low leachability cake which minimizes much of the landfilling problem. This will also impact sludge disposal costs. **Table 10** describes how important a role low moisture solids to disposal plays, especially in a program where landfill costs are high. As **Table 10** shows, even though PACT system sludge dry weight solids may be more than an activated sludge system's solids, the wet weight amount from PACT will be less. PACT, however, has one advantage no other system has; that is, Wet Air Regeneration can be used to recover activated carbon from the waste sludge for re-use. The amount of sludge for disposal will be reduced by over 90 percent and will consist of largely n inert ash material that is very easy to handle. Wet Air Regeneration, in effect, eliminates sludge disposal problems.

IX. WET AIR REGENERATION (WAR)

WAR is essentially a Wet Air Oxidation system which is designed to operate at a temperature in the range of 230° to 260° C. In this temperature range, the biological fraction of the waste sludge can be destroyed along with simultaneous destruction of the adsorbed organics. The carbon itself is left largely unaffected. A flow diagram describing the PACT/WAR system is shown in **Figure 3**. The waste sludge from PACT is fed to the WAR system as a slurry (no need to dewater first) and the regenerated product from the WAR unit can be returned directly to the PACT system for reuse.

During the regeneration process, a small amount of the carbon will be destroyed, usually on the order of 5 to 10 percent. Any ash buildup due to this oxidation of carbon during regeneration can usually be removed from the WAR system with a simple blowdown procedure. In cases where large amounts of suspended ash enters the treatment plant from outside sources, its removal can be via controlled blowdown or an ash elutriation

system. The 2.2 MGD PACT/WAR system at the Unocal refinery has been operating for over two years using only the simple blowdown procedure for ash removal.

When a PACT® system utilizes WAR, the sludge for disposal consists only of the ash material that is periodically removed from the system, and as mentioned previously, amounts to only 10 percent or less of the sludge that would require disposing with the PACT system alone. Most importantly, this resultant ash is largely inert, no offensive, and passes EPA's TCLP test.

X. REDUCED PHYSICAL SIZE

As land costs increase, the land area required for a treatment system is often a critical issue. Often time, there are severe land area restrictions which make it almost impossible to construct an industrial wastewater treatment plant. The PACT system offers a means of reducing the area required for constructing a treatment plant.

Hydraulic detention time required for activated sludge systems will typically be 24 hours and sometimes even 5 or 10 days. This means if a refinery produces 10,000 m^3 of wastewater per day and it is determined that a hydraulic detention time of 24 hours must be used, the aeration basin volume will be at least 10,000 m^3. If the basin depth is to be 5 meters, then the area required for the basin will be 2,000 m^2. The hydraulic detention time required for a comparable PACT system may be between 25 and 50 percent of that of an activated sludge system. In this example, between 1,000 and 1,500 m^2 of valuable industrial land can be saved by reduced aeration basin volume alone.

One of the principal reasons for the ability to reduce the aeration basin volume with PACT is that the organics in the wastewater are adsorbed onto the carbon and on the average will stay in the system for a time equal to the solids residence time (SRT). With a conventional activated sludge system, there is no mechanism to retain the organics in the system and the effective treatment time is equal to the hydraulic detention time (HDT). Since a PACT system typically operates with an SRT of about 15 days, it can be said that there is a time period of 14 days for the bacteria to handle the adsorbed organics (which is independent of the HDT). This fact not only allows the reduction of plant size with PACT systems, but this added treatment time helps improve the effluent quality dramatically over that from a conventional activated sludge system.

XI. REDUCED COSTS

A major reason for use of PACT systems by industry is that it can reliably treat difficult-to-treat wastewaters at costs less than multi-step approaches such as biological plus GAC. **Table 11** gives some examples. When all treatment aspects (performance, reliability, gas emissions/odors, sludge handling/disposal) are considered, PACT will be a far more reliable and less expensive system than more traditional treatment approaches.

XII. FLEXIBILITY ONCE OPERATIONAL

Once a conventional biological process has been designed and has been placed in operation, little flexibility exists to adjust its operation should significant changes in influent wastewater characteristics or in effluent quality requirements occur. It may require additional tankage, more equipment, or even add-on processes such as rapid sand filtration and GAC treatment. Unlike biological systems, PACT® has the ability to adjusted to changes in waste characteristics or effluent quality demands by altering:

* Solids residence time
* Carbon dose
* Mixed liquor carbon
* Carbon type
* Where and how the carbon is added.

XIII. CONCLUSION

An investment in a new treatment system or upgrading an existing system represents a substantial capital investment. It is vital that a system be chosen that can meet long term treatment goals and provide the necessary flexibility to meet varying wastewater quality, including shock loadings from accidental spills or other upstream problems. PACT systems can clearly meet these rigorous requirements which are paced on industry today.

The advantage of PACT over conventional biological treatment and biological treatment plus GAC can be summarized in **Table 12** and **Table 13**, respectively.

The features of tertiary quality treatment, VOC/odor control, toxicity removal, color removal, reduced size, operational flexibility, and the potential for reducing sludge by 90 percent make PACT a leading choice for industrial wastewater treatment. It is a technology that can easily meet today's requirements and those of the future.

Table 1

ZIMPRO PASSAVANT ENVIRONMENTAL SYSTEMS, INC.
SOME PACT® SYSTEM USERS

DuPont
General Electric
Bofors-Nobel*
Exxon
Tenneco
Alcoa
Crompton-Knowles
Moore Business Forms
Huron Valley Hospital
Ciba-Geigy
Powell-Duffryn
Central Services Inc.
Domtar
Yukon Ltd.
BPCL Refinery*
Unocal*
Elixir Industries

Citrus County Landfill
Reilly Industries
BP Oil
Bostik
Greater Lebanon Landfill
Phillips Petroleum
Waste Management of North America, Inc. Landfill
Burlington County Landfill
Safety Kleen
Aldrich Chemical
Nalco
Koppers
Rollins Environmental
BKK Landfill
Tosco
Bethlehem Steel
Koch Refinery
Charlotte County Landfill
Greater Lebanon Landfill

* Wet Air Regeneration

Table 2

PACT® SYSTEM PERFORMANCE RESULTS
ORGANIC CHEMICALS WASTEWATER

COMPOUND	PACT® Performance*		EPA
(all values in micrograms/Liter)	In	Out	
Acenapthene	520	nil	22
Acrylonitrile	11,700	nil	96
Benzene	290	1	37
Carbon Tetrachloride	860	1	18
Chlorobenzene	31	5	15
1,2,4-Trichlorobenzene	210	0.21	68
1,2-Dichloroethane	210	1	21
1,1,1-Trichloroethane	4,970	1	21
1,1-Dichloroethane	640	1	22
1,1,2-Trichloroethane	30	5	21
Chloroethane	667	0.65	104
Chloroform	1,470	1	21
2-Chlorophenol	31.9	0.05	31
1,2-Dichlorobenzene	30	5	77
2,4-Dichlorophenol	19	1.33	39
2,6-Dinitrotoluene	1,100	55	255
Ethylbenzene	185	1	32
Methylene chloride	84	20	40
Methyl chloride	138	0.41	86
Napthalene	191	1	22
Nitrobenzene	330	0.33	27

COMPOUND	PACT® Performance*		EPA
(all values in micrograms/Liter)	In	Out	
2-Nitrophenol	216	13	41
4-Nitrophenol	1,100	33	72
2,4-Dinitrophenol	140	1.4	71
Phenol	2,400	2	15
Bis (2-ethylhexyl) phthalate	561	2	103
Diethyl phthlate	88	1	81
Dimethyl phthlate	332	1	19
Tetrachloroethylene	304	1	22
Toluene	2,730	1	26
Trichloroethylene	326	1	21
Total Cyanide	60.1	0.65	420

* Actual results of full-scale or pilot testing of the PACT® system on wastewater. Full reports available.

** Maximum monthly average, U.S. EPA regulations.

Table 3

PACT® SYSTEM PERFORMANCE RESULTS
REFINERY WASTEWATER

Treatment Performance	PACT® Influent	PACT® Effluent
COD, mg/l	616	129
BOD_5, mg/l	149	<6
Suspended Solids, mg/l	31	7
NH_3-N, mg/l	16.1	<1
Cyanide, mg/l	4.78	0.154
Phenols, mg/l	9.55	0.053
Color, APHA Units	109	38
Oil & Grease, mg/l	14.8	0.7
Toxicity		
Rainbow Trout (LC50 - 96 hours)	---	>100
Sea Urchin (NOEC), %	---	>90
Sea Urchin (LOEC), %	---	>90
Water Flea (NOEC), %	---	>90
Water Flea (LOEC), %	---	>100

LC50 = concentration of sample in water which achieves 50 percent fish mortality in 96 hours.

NOEC = No Observable Effect Concentration.

LOEC = Lowest Observable Effect Concentration.

Table 4

METALS TREATMENT PERFORMANCE COMPARISON
ORGANIC CHEMICALS WASTEWATER

	Influent Water	PACT®	Activated Sludge
Copper, mg/l	0.41	0.07	0.36
Nickel, mg/l	0.52	0.24	0.35

Table 5

TREATMENT OF AN ORGANIC CHEMICAL
MANUFACTURING WASTEWATER

	BOD	TOC	Color	LC50*
Influent	320	245	5,365	---
Activated Sludge Effluent	3	81	3,830	11
PACT® Effluent @ Carbon Dose				
@ 100 mg/l	3	53	1,650	33
@ 250 mg/l	2	29	323	>75
@ 500 mg/l	2	17	125	>87

* based on mysid shrimp

Table 6

AMMONIA REMOVAL (NITRIFICATION) COMPARISON

A) INDUSTRIAL WASTEWATER		
Performance Results	**PACT®***	**Oxygen A.S.****
Influent, mg/l		
BOD_5	268	92
COD	680	249
TKN	32.0	19.9
NH_3-N	17.9	17.0
Total N	33.6	---
P	7.6	---
SS	---	---
Effluent, mg/l (Filter Effluent)		
BOD_5	0.2	15
COD	76	92
TKN	5.5	18.6
NH_3-N	2.0	19.3
Total N	15.6	---

* Influent to single-stage PACT® system; has wet air regeneration.

** Second stage of a two-stage biological system.

Table 6 (continued)

	B) COKE OVEN GAS LIQUORS		C) REFINERY WASTE	
Performance Results	**PACT®**	**Activated Sludge**	**PACT®**	**Activated Sludge**
Influent, mg/l				
BOD_5	1,050	650	---	---
TOC	---	---	74	74
COD	2,359	1,329	295	295
NH_3-N	13	600	19.3	19.3
Phenol	468	150	4.0	4.0
SCN	279	130	---	---
Cyanide	7	---	---	---
Effluent, mg/l (Filtered Effluent)				
BOD_5	4	10	---	---
TOC	---	---	12	25
COD	289	436	28	66
NH_3-N	<1	731	0.1	5.1
Phenol	<1	<1	0.002	0.019
SCN	<2	3.5	---	---
Cyanide	1.2	---	---	---

Table 7

NITRIFICATION PERFORMANCE COMPARISON
PACT® vs ACTIVATED SLUDGE

	PACT®*	PACT®*	Activated Sludge
Aeration Time, hrs.	3.2 - 4.5	4.6	6.2
SRT, days	13	16	16
Temperature, °C	20	10	20
Performance Results			
Influent, mg/l			
BOD_5	134	72	128
COD	364	263	320
TKN	39.4	28.3	32.0
NH_3-N	19.5	16.4	19.8
Total N	40.4	31.2	34.5
Effluent, mg/l (Clarifier Effluent)			
BOD_5	1.2	0.4	24
COD	50	30	63
TKN	3.7	2.8	6.4
NH_3-N	0.2	0.1	3.6
Total N	20.2	8.8	22.2

* Includes Wet Air Regeneration

Table 8

PACT® TREATMENT OF AN INDUSTRIAL WASTE HIGH IN VOLATILE ORGANIC CARBON (VOC)

Analysis: mg/l	PACT® Influent	PACT® Effluent
COD	1,470	110
BOD_5	740	6
NPOC	470	6
1,1,2,2-Tetrachloroethane	240	0.11
Trichloroethylene	112	0.085
cis-1,2-Dichloroethylene	107	0.023
Vinyl Chloride	37	<0.01
Acetone	22	0.077
Ethyl Ether	5.3	0.004
Ethyl Acetate	1.23	0.058
n-Butanol	145	<0.5
Isopropanol	34	<0.5
Methanol	40	<0.5
Iron	50	1.2

<1% of the VOCs stripped out of the aeration tank

Table 9

FATE OF TOXIC ORGANICS
% of Influent

	ACTIVATED SLUDGE		PACT® @ 100 MG/L CARBON DOSE	
Compound	**Effluent**	**Off-gas**	**Effluent**	**Off-gas**
Toluene	<1	17	<1	0
o-Xylene	<1	25	<1	0
1,2-Dichlorobenzene	6	59	<1	6
1,2,4-Trichlorobenzene	10	90	<1	6
Lindane	>95	0	<1	0

% Treatment = 100 - (Effluent + Off-gas)

Table 10

SLUDGE DISPOSAL COST COMPARISON*
PACT® vs ACTIVATED SLUDGE

For a 0.3 MGD industrial wastewater treatment facility having an influent COD of 1,000 mg/l.

	Activated Sludge*	PACT® System
Dry Weight Solids to Disposal		
Biosolids, lb/d	500	500
Powdered Carbon, lb/d	0	250
Total, tons/yr	91	137
% Solids to Disposal	15	40
Wet Weight to Disposal, tons/yr	608	342
Annual Disposal Cost (Chemicals):		
Powdered Carbon @ 0.40/lb	0	$ 36,000
Polymer Conditioning @ $2/lb	$ 2,000	0
Disposal (Class 1 Landfill) @ $200/ton	$122,000	$ 68,000
TOTAL DISPOSAL COSTS	$124,000	$104,000

* In order to meet U.S. EPA discharge standards, activated carbon was required. The PACT® system was able to meet such standards, activated sludge was not unless sand filtration plus GAC was also used. The costs for GAC disposal are not included herein.

Table 11

COST COMPARISON DATA
PACT® vs CONVENTIONAL TREATMENT
(Basis: U.S. $, United States Installation)

1. Large Organic Chemicals Plant

	PACT®	Activated Sludge + GAC
Capital Cost, $ in thousands	24,760	33,420

* PACT® also saves in excess of $1 million/yr in operating costs.

2. High Strength Fuels Industry Wastewater Treatment (5 MGD)

	ACTIVATED SLUDGE		PACT®	
	Incin. of Residuals	Land Trt. of Residuals	MHF Regen.	Wet Air Regen.
Capital, ($ in thous.)	9,861	6,769	6,760	5,788
Annual Net Operating (in thous.)	2,347	1,799	2,460	1,763

3. Industrial & Domestic Wastewater Facility

A. PACT® vs Conventional

	PACT®/Wet Air Regeneration (WAR)	Activated Sludge + GAC
Capital Cost, $ in thous.	4,140	6,983
O&M Cost, Annual $ in thous.	262	506

Table 11 (continued)

B. Regeneration Options for PACT®

	WAR**	Furnace Regen.
Power	$18.92	$16.30
Fuel	0	$43.20
Labor	$11.00	$32.00
Maintenance	$ 3.84	$ 6.26
Total, $/ton	**$33.76**	**$97.76**

** WAR was also $0.5 million less in capital than furnace regeneration when dewatering and all pollution control devices were included.

Table 12

ADVANTAGES OF PACT® OVER CONVENTIONAL BIOLOGICAL TREATMENT

PACT® Systems:

* Remove non-biodegradable priority pollutants
* Maintain treatment stability despite the complex and variable nature of many wastewaters
* Produce effluents that meet bio-assay standards
* Minimize VOC stripping into the air
* Remove color
* Control odor
* Increase the operational flexibility of the treatment system
* Provide some metals adsorption
* Produce less wet solids for disposal

Table 13

ADVANTAGES OF PACT® OVER CONVENTIONAL BIOLOGICAL TREATMENT FOLLOWED BY GAC COLUMNS

PACT® Systems:

-- Maintain stable treatment of complex, variable wastewaters because the carbon is a part of the systems mixed liquor, thereby protecting the biomass from shock loading.

-- Improve treatment performance due to the synergism between the powdered activated carbon and biomass in the mixed liquor.

-- Minimize VOC stripping into the air, eliminating the need for covered tanks.

-- Control odors.

-- Provide some metals adsorption.

-- Require less carbon than GAC columns do.

-- Use powdered activated carbon (PAC) which is less expensive per pound than granular activated carbon (GAC).

-- Do not require pre-filtration for suspended solids removal.

-- Have a greater number of operating variables, thereby increasing the operational flexibility of the system.

PACT[R] GENERAL PROCESS DIAGRAM

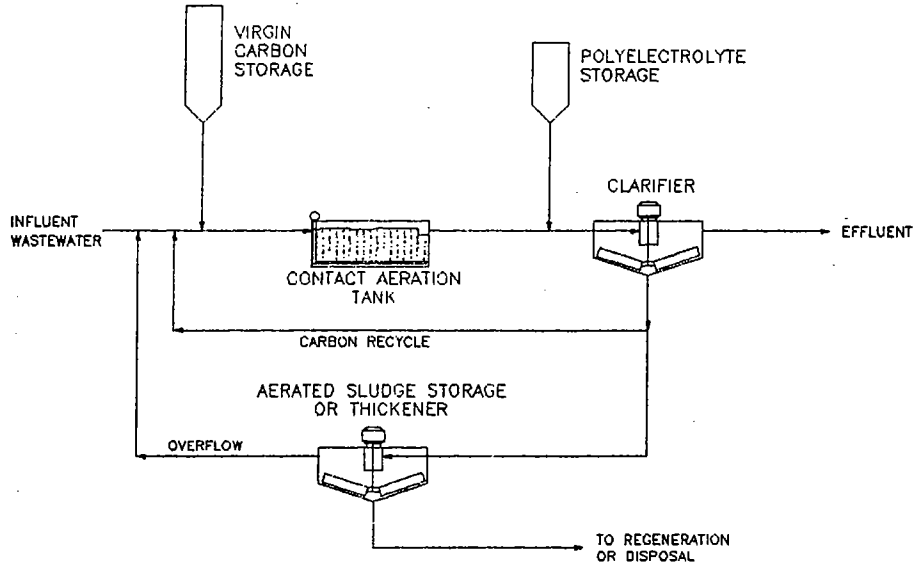

FIGURE 1

GENERAL PROCESS DIAGRAM PACT[R] – WET AIR REGENERATION SYSTEM

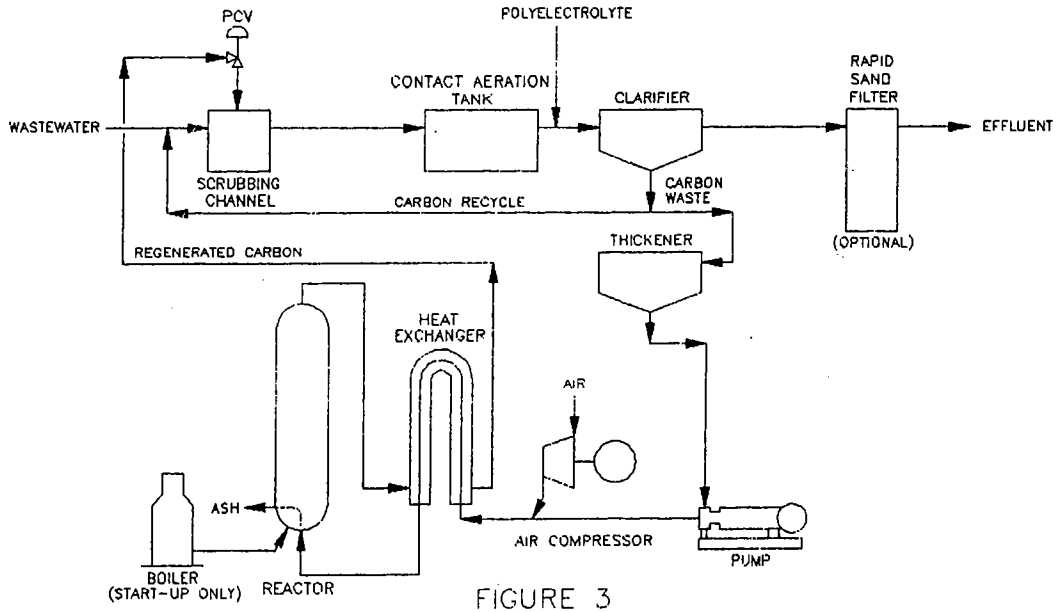

FIGURE 3

COMPARATIVE SETTLING CHARACTERISTICS
OF PACT^{R} AND ACTIVATED SLUDGE

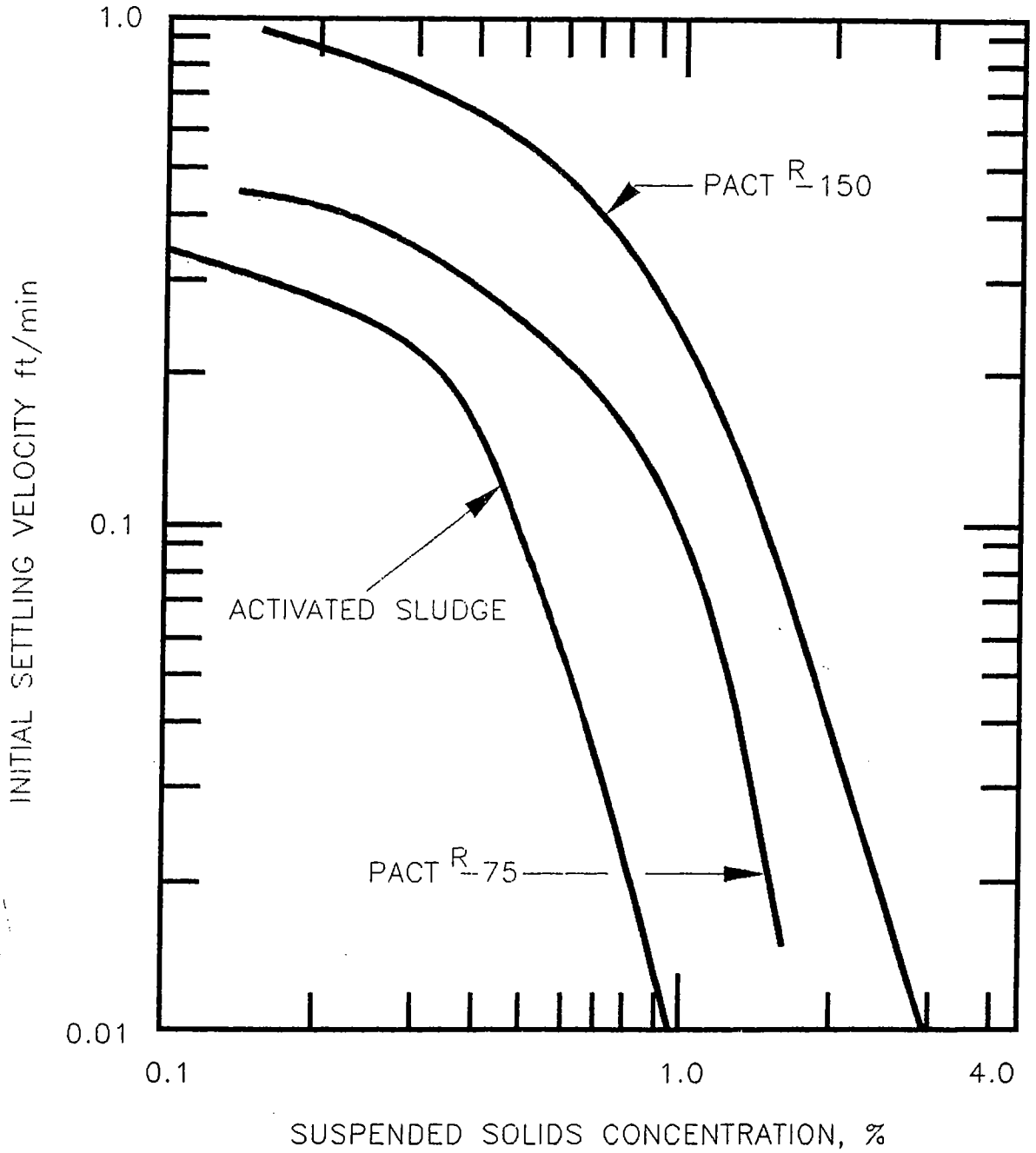

FIGURE 2