

Technical Report No. 097

Use of the PACT® System to Treat Industrial Wastewaters for Direct Discharge or Reuse

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Presented at:

Jubilee XX Conference of Science & Technology
City of Katowice, Poland
October 14-15, 1999

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I. Introduction

For many years there has been a real concern over the discharge of industrial pollutants into our world's waterways because of their often times complex chemical structure and their long term persistence in nature. One wastewater treatment technology that can treat both conventional and complex organic pollutants from industry, however, is the PACT® wastewater treatment system. The system is being used, worldwide, on a number of industrial wastewaters to accomplish a high degree of treatment of these wastewaters, allowing the product water to be safely discharged to the environment, or reused back in production from where it came.

The following paragraphs will discuss the PACT system itself, its merits in treating industrial wastewaters, how its treatment residuals can be handled, and a number of case histories to help amplify its merits when a high quality water is needed for direct discharge and/or water reuse within the industrial plant.

II. The Basic Powdered Activated Carbon Treatment (PACT®) System

Historically, granular activated carbon has been used to treat (adsorb) dilute concentrations of toxic and metal substances to tertiary levels. However, the use of such a physical treatment step alone is often not adequate since desorption phenomena occur (chromatographic effect) under transient loading conditions, thus causing release of previously adsorbed materials/toxics. A 1970's development by DuPont and Zimpro, however, takes advantage of the high adsorption rate and capacity that powdered activated carbon has for organics, and combines it with a biological wastewater treatment system. This powdered carbon enhanced activated sludge system not only removes complex industrial pollutants and toxics from wastewater, but also reduces the tendency of upsetting the active biological population in the biological treatment unit, thus allowing both physical adsorption and bio-oxidation/stabilization to occur simultaneously.

A. The System

The powdered carbon process as it is designed today will effectively treat conventional and non-conventional pollutants. The process, the PACT® wastewater treatment system, adds powdered activated carbon to a biological process, most often as described by Figure 1. In this flow-scheme, the PACT® system involves the use of powdered carbon and bacteria (activated sludge) together, effecting treatment in a single process step. Though the majority of PACT® systems in operation today use this flow-scheme, others employ powdered carbon in batch or multi-stage processes using anaerobic, anoxic, oxic treatments or combinations thereof to greatly enhance the treatment of those biological systems. More than a simple combination of carbon adsorption and biotreatment is provided, however. The advantages of this combination treatment are described below.

B. Performance Advantages

1. Organics Removal

Carbon adsorption in the PACT® system provides a mechanism for completely removing complex organics and toxic/inhibitory substances as a result of the system's adsorption and bio-oxidation characteristics. Organics are retained in the system for the period of time approaching the solids residence time (SRT) of the system rather than the hydraulic detention time as would occur in a conventional biological treatment process. This phenomena is best described by Figure 2 and Table 1.

Figure 2 shows TOC to be asymptotic at 90 ppm TOC for activated sludge (AS) treatment, meaning that no matter how much bacteria are in contact with the wastewater, residual TOC will not be lower than 90 ppm. The PACT® system, however, under a constant carbon dose, is able to reduce the TOC much further, depending on SRT and type of carbon.

That this reduction is not solely related to carbon adsorption but a synergism between the carbon and biomass shows up when treating the 1,4 dioxane in the wastewater of a synthetic fiber manufacturer as shown in Table 1. The 1,4 dioxane waste as described herein is not treatable by separate AS or GAC processes. But with PACT®, the 1,4 dioxane is fully treated - confirmation having been shown that carbon "bio-catalyses" the reaction whereby treatment now occurs biologically.

Table 1
PACT® System Treatment of a Synthetic
Fiber Manufacturing Wastewater*

Analytical Parameter, mg/L	Influent	Effluent
1,4-dioxane:	542	1.0
2-methyl -1-dioxolane:	2,540	1.4
COD:	11,950	216
BOD ₅ :	2,560	< 6
NPOC:	5,440	38

*Not treatable by separate biological means, granular carbon adsorption means, or by combined bio + GAC means

2. Stability

Maintaining a large quantity of powdered activated carbon adsorbent in the PACT® system provides stability against shock and variable organic loadings. With the presence of powdered activated carbon in the system, the mechanism of carbon adsorption exists to remove shock loads, protecting the living biology in the system from upstream upsets and toxic spills to the sewer. With PACT, for instance, the treatment operator can immediately adjust carbon dose/carbon mixed liquor, or type of carbon added to control a spill, whereas there is no such “adjustment” possible with a conventional biological system. Even tertiary activated sludge + GAC cannot offer the protection afforded by PACT since no carbon is present within the activated sludge process to protect the biology. These PACT adjustment features make it easier to meet permit or recycle water.

For example, comparative testing for phenolics removal showed that PACT® treatment of a phenols manufacturing wastewater containing 150 mg/L of phenol was possible to levels below 10 ppb whereas activated sludge at a hydraulic detention time two (2) times greater than PACT® was not able to achieve an effluent of <100 ppb phenol. Stability of performance of the two systems is best described in Figure 3 where effluent phenol scatter is much less prevalent in the PACT® system than in the activated sludge system.

3. Removal of Toxics/Priority Organics

PACT® is able to reduce toxics to far lower levels than conventional treatment processes. A comparative PACT® and activated sludge study showed that chlorinated aromatic hydrocarbons (R-C1) were far lower in concentration in the PACT® effluent than in the activated sludge effluent (see Table 2), even though activated sludge solids residences times were more than two times higher than PACT®, and even though R-C1 levels to PACT® were spiked to as high as 106 mg/L with no spiking done to activated sludge.

Table 2
Treatment of Organic Chemicals Production Wastewater
Activated Sludge vs. PACT® System Performance

	Influent	Activated Sludge Effluent	PACT® System Effluent
BOD ₅ , mg/L	4,035	17	11
COD, mg/L	10,230	296	102
TOC, mg/L	2,965	65	25
R-C1, mg/L	5.08	0.91	0.10
Phenol, mg/L	8.1	0.22	0.01
Color, APHA Units		820	94

Also, extensive testing at DuPont's Chambers Works Plant, Table 3, reports similar results. Generally, it is found that volatiles, aromatics and acid extractables are well removed.

Table 3
Priority Pollutant Removal By
The PACT® System & Activated Sludge System
DuPont Chambers Works Wastewater

Pollutant	Feed, ppb	Percent (%) Removal	
		Activated Sludge	PACT® System
Base-Neutral Extractables			
1,2-dichlorobenzene	18	90.6*	> 99.0
2,4-dinitrotoluene	1,000	31.0	99.0
2,6-dinitrotoluene	1,100	14.0	95.0
Nitrobenzene	330	94.5*	> 99.9
Acid Extractables			
1,4-dichlorophenol	19	0	93.0
2,4-dinitrophenol	140	39.0	> 99.0
4-nitrophenol	1,100	25	97.0

*aeration stripping a factor (see paragraph 5 below)

4. Improved Effluent Bioassays

Though concentration analyses of components in waste discharges are important, a significant consideration is the discharges' impact on the biota in the receiving estuary/stream. In the U.S., for example, the Environmental Protection Agency uses an integrated strategy consisting of both chemical and biological methods to address toxicity and non-conventional pollutants from industrial and municipal sources. Though conventional treatment systems may have a difficult time in achieving satisfactory results, it has been demonstrated that PACT® is able to effectively reduce toxicity of wastewater treatment plant discharges. Table 4, for instance, shows that the LC₅₀ (effluent concentration as a percent which produces immobilization of 50% of the test species) for PACT® is far better than for the extended air activated sludge process. The big advantage of PACT® over activated sludge is, that should improve performance be necessary, only a simple adjustment of carbon would be necessary.

Though a number of variables can affect effluent bioassays (such as organics, heavy metals, ammonia nitrogen, etc.), U.S. Filter/Zimpro's work with a wide range of customers has shown that total organics has a significant impact on bioassay performance. The bioassay results described by effluent COD show that LC₅₀'s improve as effluent COD decreases. It has been Zimpro's experience that COD and TOC better describe this type of relationship-BOD does not.

Table 4
Treatment of a Chemical Manufacturing Wastewater

	BOD	TOC	Color	Cu	Cr	Ni	LC₅₀*
Influent	320	245	5,365	0.41	0.09	0.52	
Extended Air Activation Sludge Effluent	3	81	3,830	0.36	0.06	0.35	11
PACT® Effluent @							
@ 100 mg/L	3	53	1,650	0.18	0.04	0.27	33
@ 250 mg/L	2	29	323	0.07	0.02	0.24	>75
@ 500 mg/L	2	17	125	0.04	<0.02	0.23	>87

*based on mysid shrimp

5. Control of VOC Stripping

Attention thus far has focused on effluent quality without regard to air quality, an area where toxics can escape the treatment process and impact air quality.

A concern in regard to off-gas quality is the tendency to strip volatiles out of the conventional treatment system while aerating and, thus, not truly treat the volatile organic species. In this regard PACT® has been shown to be able to control organic emissions much more effectively than conventional biological processes.

PACT systems will effectively remove biodegradable and poorly degradable compounds without stripping them. Stripping of volatiles is highly likely out of activated sludge, however, as noted in Table 5. Addition of powdered carbon to the aerator increases volatiles retentivity and nearly eliminates volatiles stripping.

Table 5
Fate of Toxic Organics, % of Influent

Compound	Activated Sludge		PACT @ 100 mg/l Carbon Dose	
	Effluent	Off-Gas	Effluent	Off-Gas
Toluene	< 1	17	< 1	0
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

The minimization of stripping out of the PACT® system was confirmed in PACT® testing done for a major U.S. petroleum refinery. Data as shown in Figure 4 readily shows that the PACT® system is able to easily control benzene, even for the case here in which 80 mg/L benzene was found in the influent to PACT and in which gaseous benzene was simultaneously added to the air being supplied to the aeration tanks.

6. Reduced Physical Size

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

Hydraulic detention times required for activated sludge systems to treat refinery wastewater will typically be 24 hours. This means if a refinery produces 10,000 m³/d of wastewater, an aeration tank volume will be 10,000 m³. If the basin depth is to be 5 meters, then the area required for basin will be 2,000 m². However, 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 m² 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 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 a SRT of about 15 days, it can be said that there is a time period of 15 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 convention activated sludge system.

C. Residuals Management

Proper residuals (waste solids) management is an important aspect for any system since residuals could carry the concentrated form of the toxic being treated in the wastewater treatment step to a point outside the treatment plant. Residuals from the treatment of toxics must be treated as such unless the residuals can be shown to contain no leachable toxics.

1. Sludge Dewatering

In the PACT system, for instance, it is generally been U.S. Filter/Zimpro's experience that the spent residuals would not contain toxic organics, even though toxics are being treated by the system. This aspect of the system is demonstrated in Figure 4 where the mass balance shows little to no benzene in the PACT sludge. (This is far different than GAC columns which sorb organics and hold those organics on the surface of the GAC; in effect concentrating the material in the GAC bed. The GAC, in this case, then becomes a hazardous waste.)

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. PACT® system sludges, however, will have far less cake moisture (40-50 percent water). Table 6 describes how important a role low moisture solids to disposal plays, especially in a program where landfill costs are high. As Table 6 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.

Table 6
Sludge Disposal Cost Comparison
PACT® vs. Activated Sludge

For a 1,100 CMD (0.3 MGD) industrial wastewater treatment facility having an influent COD of 1,000 mg/L.

	<u>Activated Sludge*</u>	<u>PACT® System</u>
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 and its disposal are not included herein.*

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.

2. Sludge Destruction/Carbon Regeneration Using Wet Air Regeneration

With PACT comes a lucrative option - being able to economically recover the spent powdered activated carbon while destroying biomass and associated organics (conventional, toxics), and being able to do so while in a slurry of less than 10% solids. That option uses wet oxidation - an aqueous phase oxidation of organics plus inorganics and a simultaneous regeneration of powdered activated carbon. The process, wet air regeneration (WAR), operates at temperatures less than 260° C and pressures less than 75 atmospheres and is shown in the general flow scheme of Figure 5.

With the WAR system, there is no need to dewater the spent PACT slurry and the regenerated product from the WAR unit can be returned directly to the PACT system for reuse.

In wet air regeneration (and wet air oxidation), the bulk of the organic waste stream is converted to carbon dioxide and water. Because of the aqueous phase oxidation, no oxides of nitrogen or sulfur exist in the off-gases. Also, oxidation of the spent carbon slurry is generally self-supporting (autogenous), requiring no outside source of fuel energy to maintain operating temperatures.

If wet oxidation regeneration were to be used with PACT, the only residuals for disposal would consist of a very small amount of blowdown ash. Though the ash may contain the oxide forms of heavy metals, the ash will be stable, sterile, and non-leaching. The ash can also be dewatered to solids concentrations as high as 70%.

During the regeneration process a small amount of the carbon will be destroyed, usually on the order of 5 to 10 percent, and is made up by the addition of virgin carbon to the PACT system.

III. PACT Systems Case Histories

There are numerous examples of U.S. Filter/Zimpro supplied PACT, and PACT + WAR systems in the world today ranging in size from 10 m³/d to over 200,000 m³/d that are successfully treating difficult to treat wastes (see Table 7). Case histories of four different sites are shown below.

Table 7
U.S. Filter/Zimpro, Inc.
PACT® Industrial User's List

Alcoa (2)	Al Jubail Fertilizer
Aldrich Chemical	BFI Landfill
Bethlehem Steel	Bostik
BKK Landfill	Bristol-Mvers Squibb
Bofors-Nobel*	Chambers Development Co.
BP Oil	Charlotte County Landfill
BPCL Refinery*	Club Toluca
Burlington County Landfill	Cuernavaca Hospital
Central Services, Inc.	Elixir Industries
Ciba-Geigy	Frederick County Landfill
Citrus County Landfill	Gadot Petrochemical
Crompton-Knowles	Greater Lebanon Landfill
Domtar	Hagerstown Fibers Ltd.
DuPont (2)	Hillsborough County Landfill
Exxon (2)	Hoechst-Celanese
General Electric	Kin-Buc Landfill
Huron Valley Hospital	Koch Refinery
Koppers	Lone Pine Landfill
Moore Business Forms (3)	Ott/Storv/Cordova Site
Nalco (3)	Phillips Petroleum
Powell-Duffryn	Polifin, Ltd.
Reilly Industries	Puebla Hospital
Rollins Environmental (2)	RCC Landfill
Safety Kleen	Schofield, WI
Southern Yeast	Shell Oil
Tenneco	TaSheh Industrial Park
Tosco	Teknor Apex Inc.
Unocal*	Thai Ambica Chemicals
Waste Management of North America.	W.N. Stevenson County Landfill
Yukon Ltd.	Western Berks Refuse Authority

*Use Wet Air Carbon Regeneration

A. Direct Discharge

1. Municipal & Industrial

The first PACT®+WAR system that will be examined is a 54 MGD (200,000 m³/d) municipal + industrial facility that has been in operation since 1985.

The city's wastewater treatment plant (WWTP) treats a highly complex mixture of domestic and industrial (pharmaceutical, pulp and paper, organic chemical) wastewaters. In 1975, the city was informed that the existing activated sludge plant had to be upgraded to achieve effluent ammonia, BOD, and suspended solids limits of 2 mg/L, 10 mg/L, and 10 mg/L, respectively.

The goal was to meet environmental needs economically, while providing a system that would allow the industrial base to grow without imposing a strict pretreatment requirement on industry.. Thus, a thorough pilot plant testing program was undertaken to determine the most effective method for treating the city's wastewater.

a. Pilot Plant Testing

1) Waste Treatment

Single stage treatment systems (extended air activated sludge, contact stabilization activated sludge, PACT with wet air regeneration) as well as multi-stage treatment systems (two-stage air activated sludge, two-stage oxygen activated sludge, air activated sludge plus second stage RBC, pure oxygen activated sludge plus second stage RBC, and pure oxygen activated sludge plus second stage PACT/WAR) were piloted.

Of all the systems tested, only the PACT/WAR system was able to consistently meet discharge standards (see Table 8 below).

Table 8
PACT®/WAR System Performance

	Primary Effluent	Effluent	Percent Reduction
BOD	268	0.2	> 99
COD	680	76	89
TKN	32.0	5.5	83
NH ₃ -N	17.9	2.0	89
NO ₃ -N	1.0	8.8	--
TN as N	33.6	15.6	54
P	7.6	2.2	71

Other related testing included: single media and multi-media rapid sand filtration; odor control testing of liquid scrubbing, ozonation, carbon adsorption, and hydrogen peroxide systems; and primary solids and primary/waste activated sludge solids conditioning.

2) Odor Control

Because the WWTP is located within the city, odors were of significant concern. The then existing activated sludge system generated a huge number of odor complaints from residents throughout the city. A comprehensive odor control testing program identified various sources of odor and concluded that, of the various methods tried, scrubbing using PACT® mixed liquor was the most effective (see Table 9). And, because using PACT mixed liquor did not cost anything for chemicals, it was by far the most cost effective.

**Table 9
Odor Control Studies**

1. Sources			
	Odor Level	Gas	Major
Grit Chamber	73	High	H ₂ S
Lift Station	43	Medium	H ₂ S
Aeration Tanks	39	High	Organic
Raw Sludge Thickeners	30	Low	H ₂ S
Sludge Processing	440	Low	Organic
Sludge Dewatering	980	Medium	Organic
2. Two Stage Scrubbing Results. % Removal			
Scrubbing Liquid	Odor	THC	H₂S
PACT®-PACT®	97	46	91
VC-VC	95	26	82
AS-AS	81	14	49
Water-3% NaOCl	68	25	98
Water-3% KMnO ₄	46	55	97

b. Full Scale Wastewater Treatment Plant (WWTP)

The activated sludge system was converted to a PACT® system in 1985. The overall system consists of primary treatment, aeration, clarification, Hydro-Clear pulsed bed sand filtration, and chlorination prior to discharge to the river. Spent carbon is wasted to a gravity thickener prior to being autogenously wet air regenerated.

WAR operates autothermally at about 230°C as long as feed solids exceed about 6%. Residual heat energy from operating WAR units can be used for WWTP building heat, if desired.

The PACT® system controls all odors from throughout the WWTP by collecting all foul odors and sending them, via the aeration blowers, to the PACT® aeration tanks. Results have shown that no odors whatsoever escape the aeration system, even on hot, humid summer days.

Excellent treatment performance has been obtained since plant start-up, as shown in Table 10 below.

Table 10

WWTP Performance, ppm mg/L		
	PACT® Influent	PACT® Effluent
BOD ₅	~ 250	< 5
COD	~ 700	< 90
SS	~ 400	< 10
NH ₃ -N	~ 20	< 0.5

And since the plant went on-line, the city has embarked on a bioassay testing program using daphnia magna, ceriodaphnia, and fathead minnows to guarantee its customers that wastes have been detoxified prior to discharge to the river. Bioassay results are equally impressive as shown in Table 11 below.

Table 11
Bioassay (Toxicity) Performance

Fathead Minnow			Ceriodaphnia		
Acute	Chronic (NOEC)		Acute	Chronic (NOEC)	
	Survival	Growth		Survival	Reprod.
> 100	100	100	100	100	100

Ultimately, the river has been the biggest beneficiary of the wastewater treatment project. Effluent from the plant is clear and undetectable at the outfall, where previously a distinct plume was visible, and water in the river was of such poor quality that it could not support a sport fish population. That is not the case today, where sport fishing, swimming, and boating are popular activities.

2. Industrial: Refinery

This 20,000 TPD far east refinery processes "high" and "middle" crude, with two main wastewater streams requiring treatment.

The concentrated wastewater stream consists of sour condensates from the catalytic cracking unit, fluidized catalytic cracking unit, and spent caustic from the Kero-Merox unit. The other stream consists of process wastewaters from the crude distillation unit, Bituminous Blowing unit, and Aromatics plant. The design characteristics of the combined wastewater stream was predicted to be as shown in Table 12 below, along with the discharge standards the refinery had to meet.

Table 12
Refinery Wastewater Characteristics

	Predicted	Discharge Standard Max. conc. (mg/L)
BOD ₅ , ppm	808	15
COD, ppm	1,172	250
Sulfide, ppm	120	0.5
Oil & grease		10
Suspended solids, ppm	57	20
pH	6 - 10	6 - 8.5

The 240 m³/hr. (1.5 MGD) treatment process (see Figure 6) consists of equalization and treatment of the combined equalized waste stream, using a free oil and emulsified oil separation system, followed by the PACT® system. The PACT® system has an aeration basin (with a diffused aeration system) and a clarifier. A guard pond stores the treated effluent prior to stream discharge.

Wasting of spent PACT® solids is to a gravity thickener, then to a slurry storage tank. This material is then sent to the 25 gpm (5.7 m³/hr) WAR unit. After regeneration, the regenerated carbon is returned to the PACT® system. A small amount of ash material is periodically removed and is dewatered in a centrifuge and trucked off site to a landfill.

The system meets all discharge standards (shown in Table 13 below), in spite of an influent COD of nearly 1,500 mg/L, demonstrating the effectiveness of the PACT®/WAR system in removing COD, phenol, and sulfides.

Table 13
PACT®/WAR System Performance

	Actual Influent	PACT® Effluent	Discharge Standard
BOD, ppm	718	7	15
COD, ppm	1,494	78	250
BOD/COD, ppm	0.5	--	--
Phenolics, ppm	70	NIL	1
Sulfide, ppm	142	NIL	0.5
Oil & Grease, ppm	--	2	10
Suspended Solids, ppm	75	6	20
pH	8	6.6	6 - 8.5

From the operating history of the plant comes the following observations:

- The sludge generated for disposal from the PACT®/WAR system is almost negligible, being only a sterile ash from the reactor blowdown.
- WAR unit operation is thermally self-sustaining at a solids concentration of 7%, easily achieved by the gravity thickener.
- When mixed liquor carbon levels in the aeration basins are allowed to fall too low, the biomass becomes inefficient, thus affecting treatment performance. However, when the carbon levels are returned to normal operating levels, rapid return of performance is seen, thus demonstrating the importance of maintaining sufficient carbon in the system to eliminate bio-toxins.
- The plant was able to withstand shock loads as well as spikes very effectively. For example, COD up to 4000 mg/l (longer duration), sulfide up to 300-500 mg/l (short duration), and phenol up to 900 mg/l (short duration) posed no problem in meeting the required treated effluent quality.
- Very high influent sulfide levels resulted in sulfur reducing bacteria converting the sulfide to sulfur and storing it in the cells. Subsequent reduction in influent sulfide levels then encourage the biomass to oxidize the stored sulfur to sulfate, thus causing a reduction in pH. Thus, it has been found beneficial to maintain sulfides within specified limits at all times.

The treatment of the refinery's wastewater by the PACT®/WAR system has shown that a high quality effluent can be produced with minimal residual solids to landfill without a concern for air pollution or the escape of toxics, odors, and color to the environment.

B. Water Reuse

1. Industrial: Petrochemical

In 1994, South Africa's largest manufacturer of plastics and leading producer of monomers (ethylene and propylene) and polymers (polypropylene and polyvinyl chloride) made a decision to reuse/recycle treated wastewater from its vinyl chloride monomers (VCM) plant so it could be used in its cyanide plant or its chlorine plant.

The main objective of the manufacturer was to purify the wastewaters from the vinyl chloride monomers (VCM) production area. However, to do so required that the purity of the product (recycled) water to the chlorine plant had to be less than 5 mg/L TOC. The VCM wastewaters from the manufacturing plant were estimated to be 120 m³/day, having a 1 g/L TOC and 2 g/L COD. Since Polifin could find no one other than U.S. Filter/Zimpro that had the treatment experience with this kind of wastewater, pilot testing at U.S. Filter/Zimpro's R & D facilities in Rothschild, Wisconsin, was undertaken using bench scale equipment.

Bench scale testing of a two stage batch PACT system began in July, 1994 with preselected HDT, SRT, and carbon dose/type using U.S. Filter/Zimpro's database information to set up the pilot equipment. Testing data showed that more than 90% removal of COD and TOC could be obtained, but a less than 5 mg/L TOC would not be achievable unless a UV oxidation post-treatment step was employed. Thus, a full scale system was configured from the bench scale work.

The overall process flow diagram of the VCM water recovery system is shown in Figure 7 below. The heart of the system uses a two stage batch PACT system which facilitates counter-current flow of carbon and wastewater. All virgin carbon addition is to the second stage of the PACT system to enable polishing of first stage effluent. The "partially-spent" carbon from the second stage is wasted to the first stage where the bulk of the organic removal occurs via an adsorption-biodegradation mechanism.

Each batch PACT unit is set up to automatically sequence as a SBR, i.e. fill, aerate/adjust pH, add carbon, add polymer, turn off air, settle, decant, and waste solids as shown in Figure 8.

Cycle times and all sequencing steps are fully adjustable through a self-contained PLC that is part of the system provided.

Effluent from the second stage PACT system is directed to a three cell, single media Hydro-Clear sand filter where product water can be taken directly to the cyanide plant, or routed through the UV/oxidation process before going to the chlorine plant.

The production facility began producing VCM and VCM wastewater in February 1996. Because of a unique acclimation method used, the PACT system immediately treated the wastewater as it became available. Quite surprisingly, effluent quality out of the PACT system was far better than anticipated by the bench scale pilot work - TOC's ran between 5 mg/L and 10 mg/L.

Because of the excellent performance of the PACT system, all product water from the PACT system could be taken directly to the cyanide plant without further treatment, whereas, if the product water was to go to chlorine, then a minor post-treatment through the UV/oxidation process was undertaken to insure that the <5mg/L TOC was obtained.

Because of PACT's performance, all wastewaters from VCM are able to be recycled and reused, achieving <10 mg/L TOC out of the Hydro-Clear sand filter to enable reuse in cyanide, or <5 mg/L TOC out of UV/oxidation to enable re-use in chlorine.

The water re-use program has been highly successful, so much so, in fact, that a 30% expansion is being planned. The manufacturer is currently working with U.S. Filter/Zimpro to determine how much, if any, additional equipment may be necessary to meet that expansion goal.

2. Refinery

A refinery in the U.S. recently had U.S. Filter/Zimpro install a 700 CMD (130 gpm) PACT plus filtration plus reverse osmosis (RO) system to enable the refinery to recover over 80% of its wastewaters, allowing reuse in the refinery's cooling tower and/or steam generation systems.

Initially, the refinery and its engineer anticipated that, in order to accomplish its reuse objectives when treating the refinery's wastes (see Table 14), biological treatment plus warm lime softening plus RO of a portion of the softened stream for boiler use would be the best approach in achieving the reuse objectives.

Table 14
Initial Waste Characterization

	Wastewater		Reuse Criteria	
	As Received	Expected Feed	Boiler	Cooling Tower
Flow, gpm	--	130	50	Remainder
BOD, mg/l	71	300	1	10
COD, mg/l ⁵	259	600	--	--
TOC, mg/l	34	200	2	20
Total Solids, mg/l	816	2,000	100	2,000
Total Ash, mg/l	620	--	--	--
Suspended Solids, mg/l	12	100	< 5	< 5
Oil & Grease mg/l	54	40	< 2.5	< 2.5
Total Kjeldahl Nitrogen, mg/l	36	--	--	--
Phenols, mg/l	0.04	20	0.005	0.1
Soluble Chloride, mg/l	47	480	24	--
Sulfate, mg/l	185	160	10	--
Hardness, mg/l	73	80	1.5	30
Silica, mg/l (as SiO ₂)	25	40	2	--
Aluminum	0.64	--	--	--
Boron, mg/l	0.5	0.300	0.002	1.5
Magnesium, mg/l	3.3	4.00	0.2	2
Calcium, mg/l	22	40	1	20
Iron, mg/l	0.54	0.500	0.01	0.1
Sodium, mg/l	117	360	20	400

Based on this evaluation, bench scale testing of the concept occurred. Drums of wastewater were received at U.S. Filter/Zimpro's R & D facility and were analyzed. What was found, as shown in the above table, was that the "as received" waste and the "expected waste" were not similar, especially the BOD/COD ratio. In this case the low BOD/COD ratio favored the use of some form of carbon to aid in organics removal. For this reason, the PACT system was the preferred choice for organics control upstream of the RO system. Bench scale PACT system testing showed good effluent quality (see Table 15).

Table 15
PACT System Performance, mg/l

	BOD	COD	TOC	O & G	PHENOLICS
Feed					
Average	90	300	52	54	1.6
Std Dev.	75	130	24	61	0.6
PACT Effluent					
Average	1.6	140	17	< 5	0.02
Std Dev.	4.6	40	5	--	0.02

A U.S. Filter/Zimpro evaluation also indicated, that instead of only treating the boiler fraction through the entire system with the cooling tower makeup portion through only PACT plus warm lime softening, it would be more efficient to treat the entire flow through PACT and a two-stage RO to eliminate the “cycle-up” of minerals that would otherwise occur. The bench scale testing also suggested that warm lime softening would only be moderately successful in removing the silica and minerals, whereas direct RO treatment of PACT effluent was a better performer and would be a viable option.

As a result of the bench scale work, on-site pilot testing was conducted over a three month period. Investigated were PACT, warm lime softening, and RO systems. Based on testing and the mineral cycle-up anticipated of not ROing the entire waste stream, the mineral content was artificially elevated to simulate “cycling-up” due to the reuse plan identified by the refiner’s engineer.

On-site pilot testing, Table 16, showed that the PACT system produced an effluent which contained low levels of organic constituents (COD, BOD, and TOC) in spite of a highly variable raw wastewater.

Table 16
Performance Comparison, On-Site Pilot Test
 All values in mg/l

Parameter	PACT Effluent	PACT Effluent, Softened, Single Pass RO	PACT Effluent, Two Pass RO
BOD ₅	< 5	--	--
COD	<87	--	--
TOC	<15	6.14	1.64
Calcium	24	1.2	1.22
Magnesium	4	0.74	0.25
Sodium	82	196.3	17.9
Sulfate	--	2.38	< 0.01
Chloride	--	207	13.4
Silica	--	11.8	1.45
Iron	--	< 0.007	0.06
Turbidity, NTU	--	1.12	< 0.1
Strontium	--	0.003	0.006
TDS as NaCl	360	334	37.8

Testing of warm lime softening using lime and MgSO₄ was successful in removing the silica and minerals found in PACT treated wastewater, but did nothing to remove soluble COD/TOC. It also showed that magnesium oxide was not effective in removing silica; magnesium chloride and magnesium sulfate, however, proved to be far more effective. Magnesium sulfate was chosen as the preferred chemical for silica removal because of the stringent chloride limit of the site's boiler and that sludge's better dewatering ability.

Reverse osmosis of the lime softened effluent met water reuse objectives for the boiler. PACT system solids were easily dewaterable without need of a chemical conditioning agent. Warm lime softening solids, on the other hand, exhibited varying degrees of dewaterability - the poorest being caustic soda softening and the best being lime + MgSO₄.

Of major importance was confirmation that direct reverse osmosis (RO) treatment of PACT system effluent proved to be very effective in reducing silica and the concentration of salts in the PACT effluent. RO testing on the PACT effluent indicated that a two pass RO configuration would be able to achieve more stringent reuse quality standards than demonstrated by the warm lime softening approach.

As a result of the overall testing program, a system was configured as shown by Figure 9. Long term testing, on-site, also showed it was possible to process PACT system effluent through filtration and RO without having to resort to lime softening and the necessity to heat the water as warm lime softening required.

All solids generated will be taken to an aerated sludge storage tank, then eventually dewatered in a recessed plate filter press. RO reject will be sewerred and discharged to the sanitary sewer of the local POTW.

Thus, the overall reuse approach allows the refinery to recover over 80% of its water and produce a boiler quality water at all times without having to worry about an organic and/or mineral buildup problem in the refinery.

PACT® Wastewater Treatment System General Process Diagram

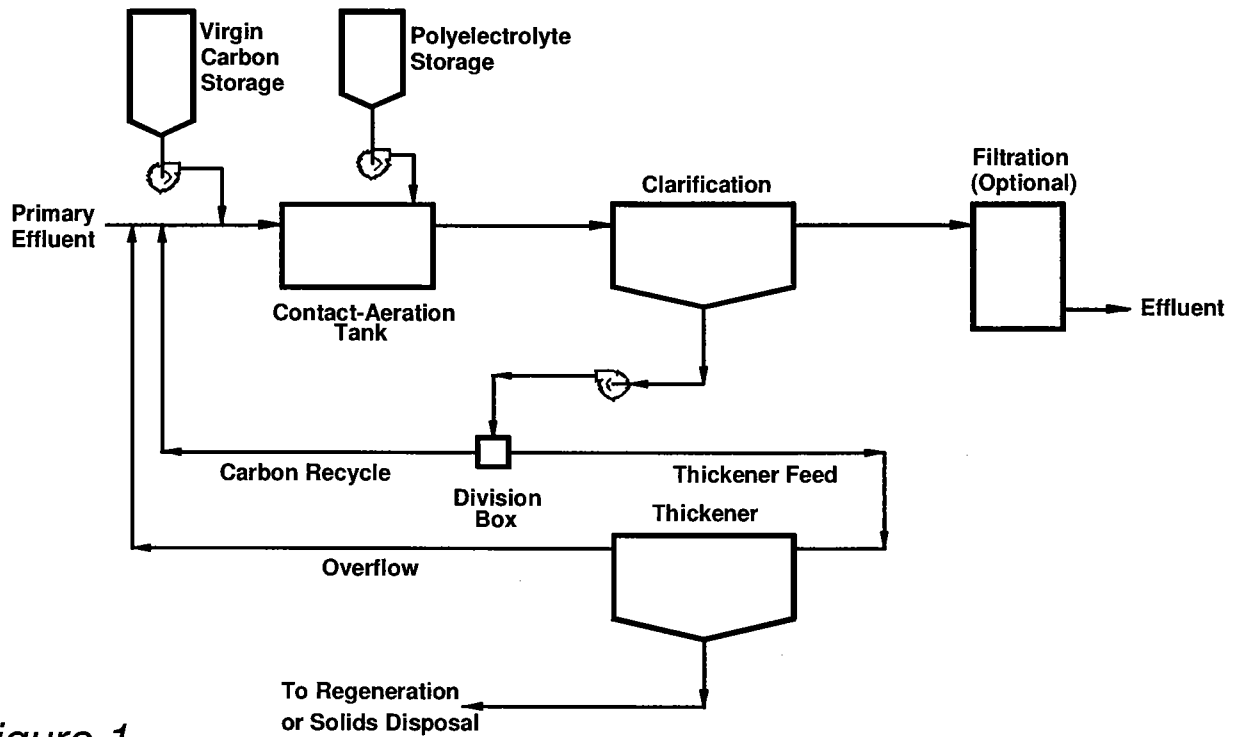


Figure 1

Effect of Sludge Age on Effluent Soluble TOC PACT® System vs. Activated Sludge

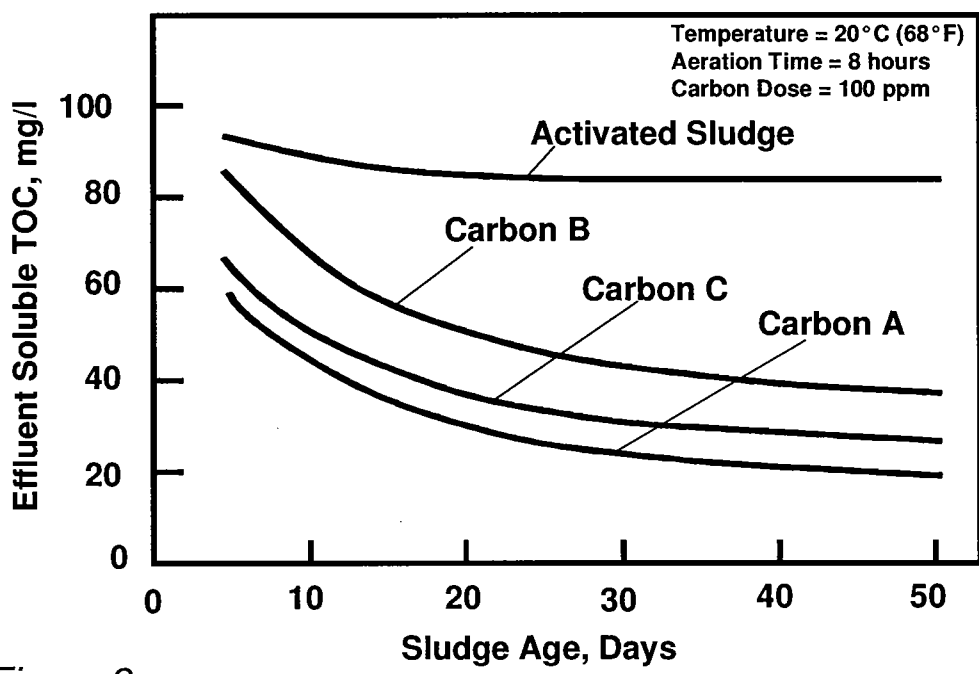


Figure 2

Effluent Phenol Variability vs. Feed COD

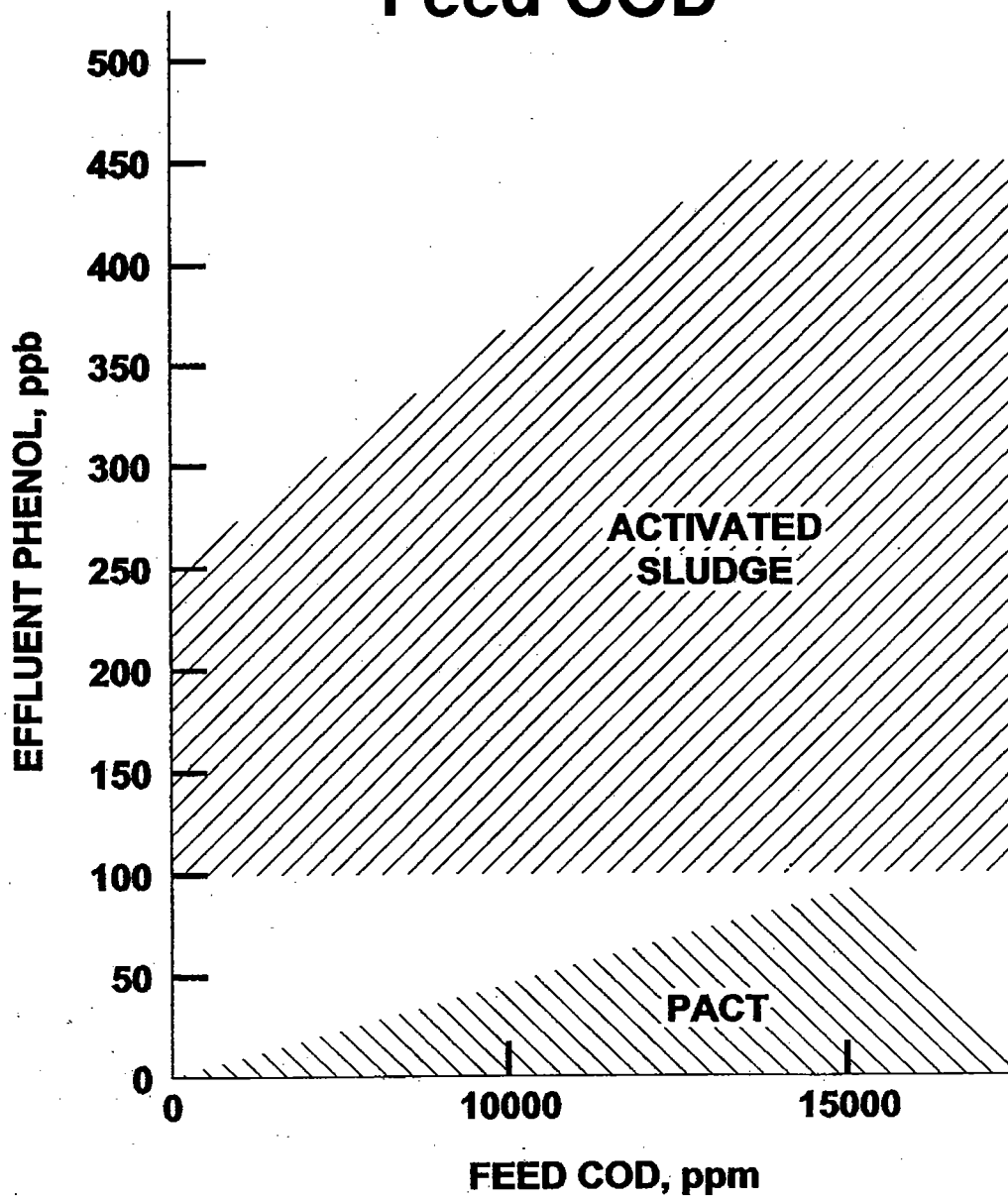


Figure 3

Benzene Material Balance *Benzene Removal Study with High VOC Air*

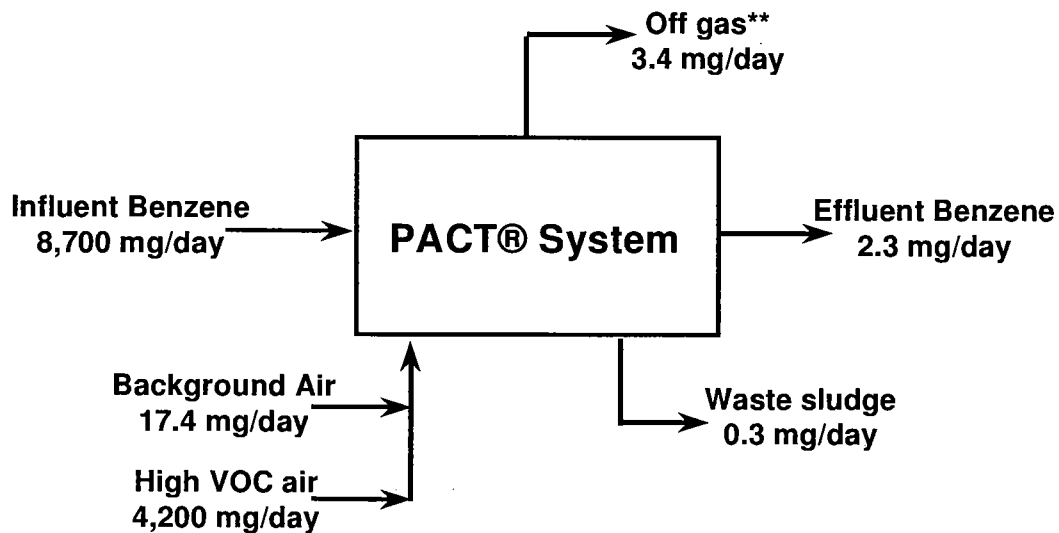


Figure 4

** 0.03% of the influent benzene was measured in the off gas.

Wet Air Regeneration System

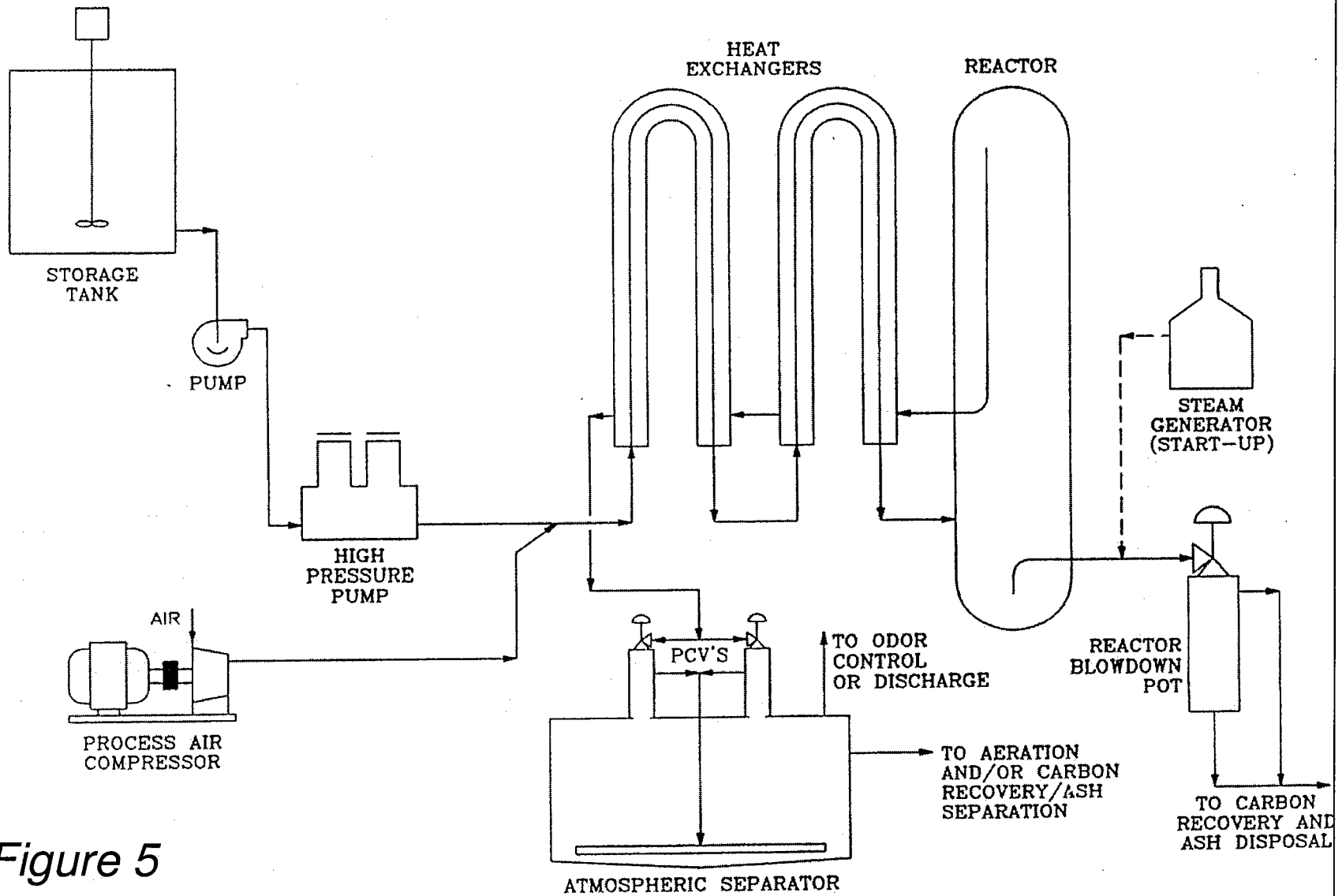


Figure 5

Refinery Waste Water Treatment Plant

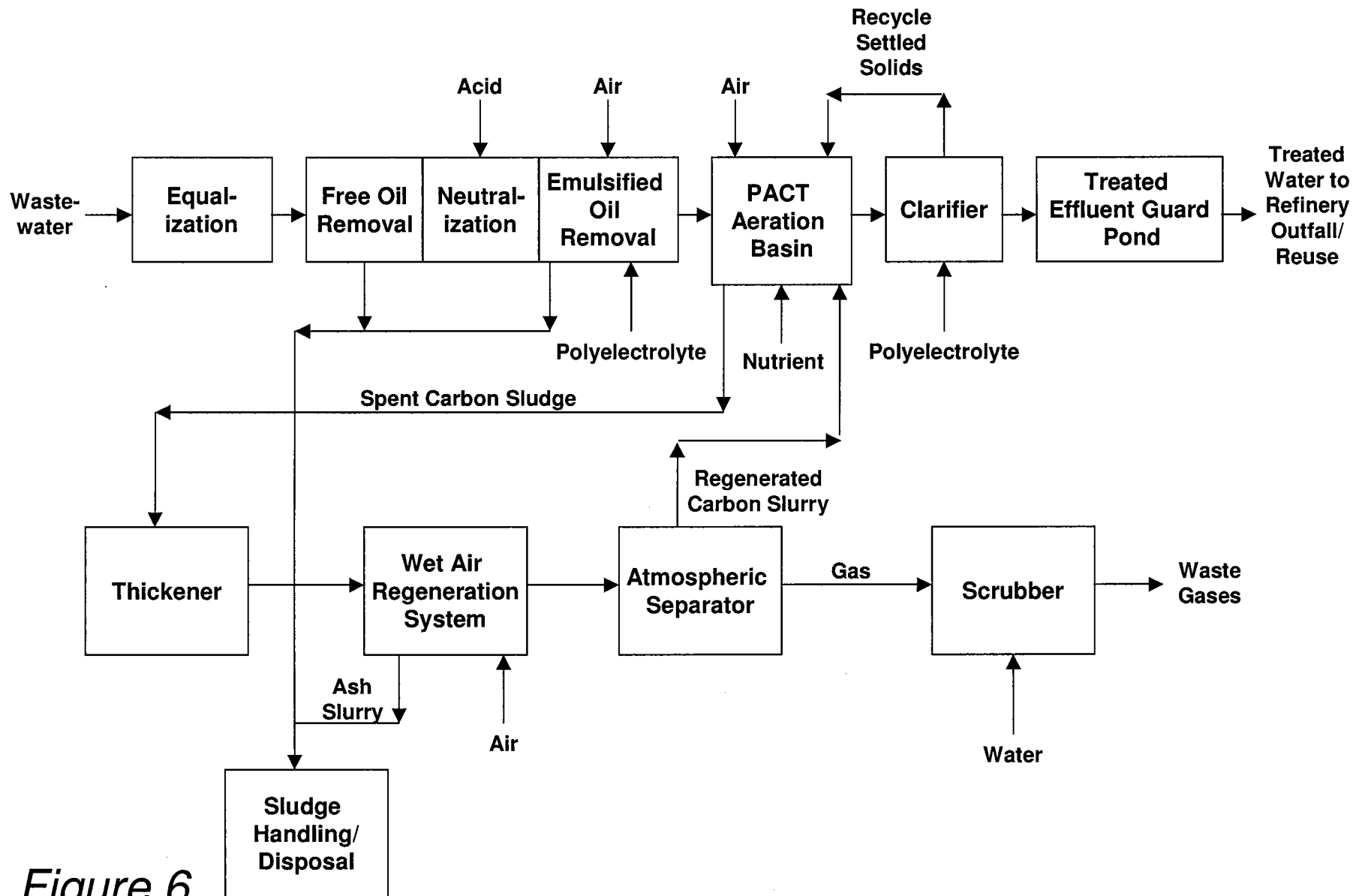


Figure 6

Water Reuse Program Polifin Ltd. Process Flow Diagram

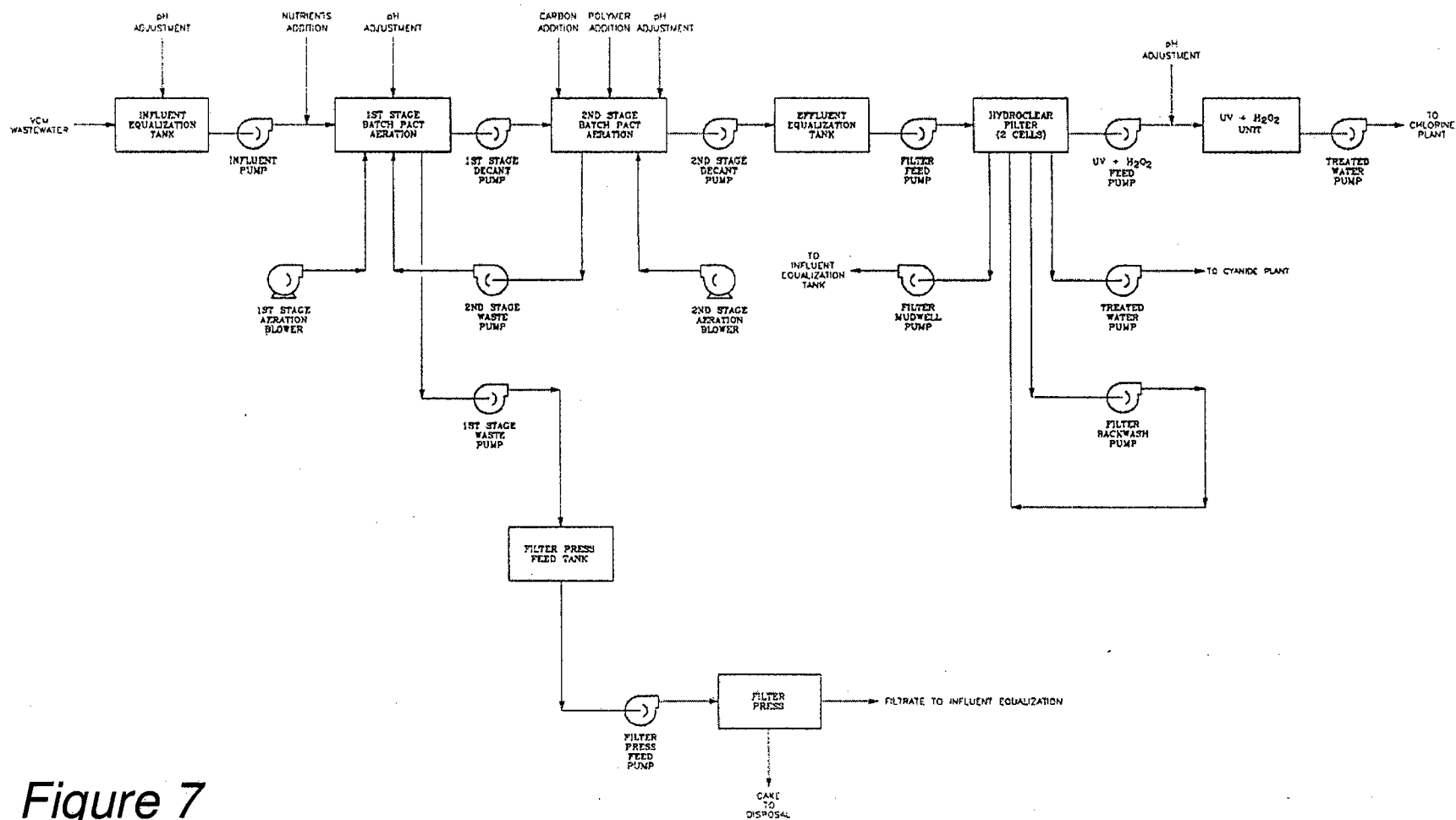


Figure 7

Batch PACT® System Diagram

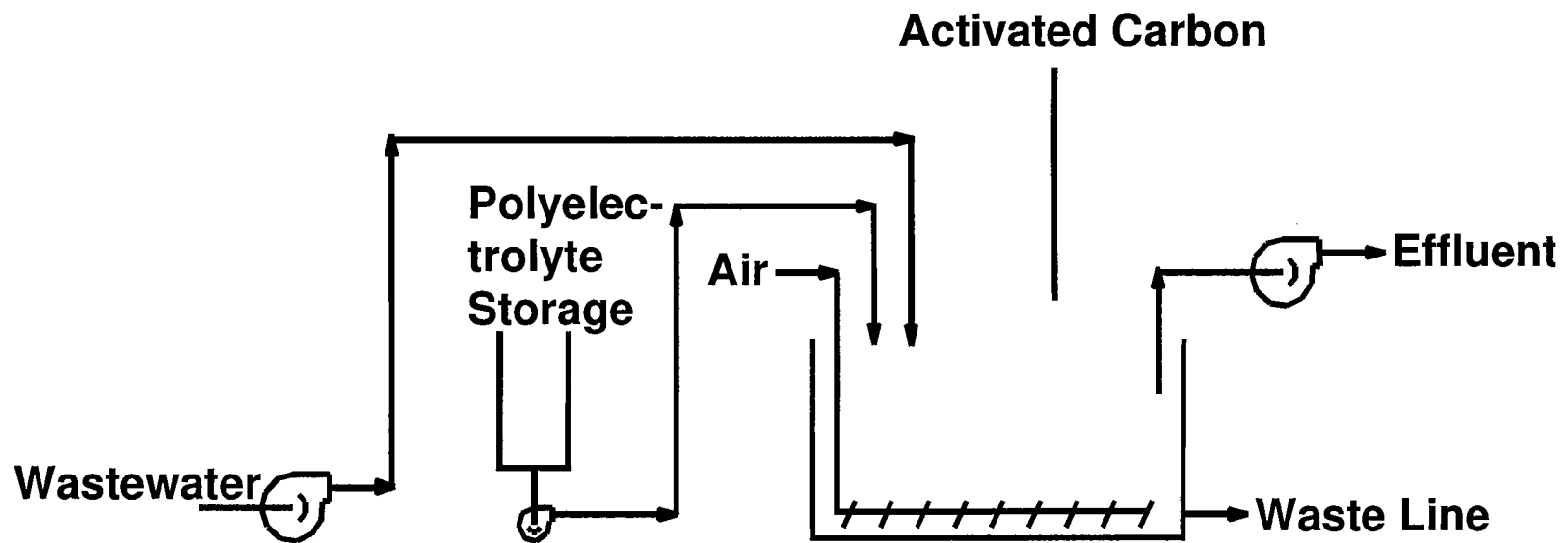


Figure 8

Batch PACT® Operating Sequence

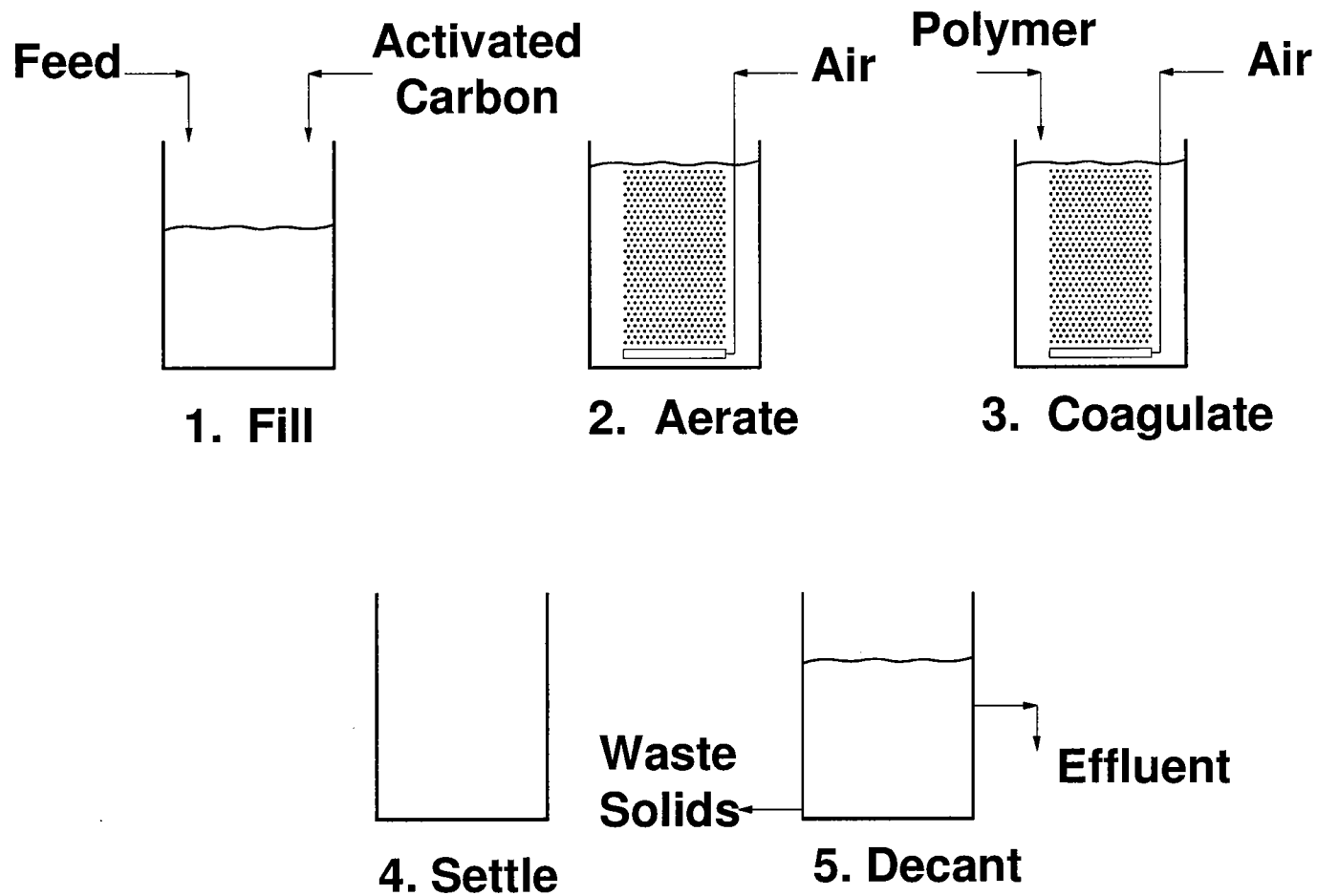


Figure 8

Process Flow Diagram Refinery Water Reuse Project (130 gpm)

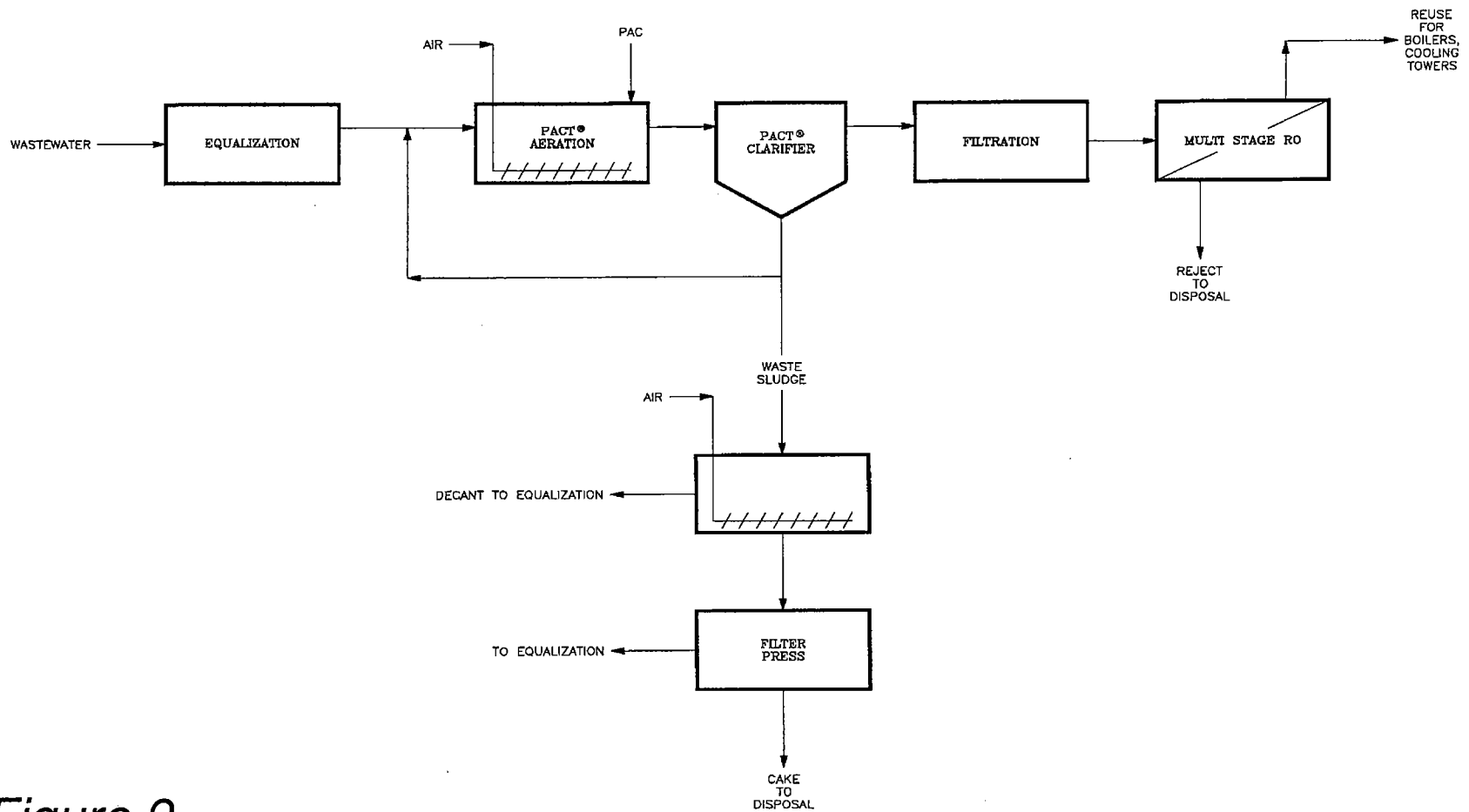


Figure 9