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Project Summary

Full-Scale Demonstration of Industrial Wastewater Treatment Utilizing Du Pont's PACT® Process

Harry W. Heath, Jr.

Operating and cost data on startup and the initial 30 months of operation of a 150,000-m³/day (40-MGD) industrial wastewater treatment plant using Du Pont's PACT® process are reported. The PACT process effectively provides both secondary and tertiary treatment by adding powdered activated carbon to the aerator in an activated sludge process.

In 1978 and 1979, performance exceeded expectations in terms of BOD_5 and color removal, 96% and 68%, respectively. Removal of Dissolved Organic Carbon (DOC) was 82%, approximately equal to the design value. Removals were consistent even though the medium-strength waste contained many relatively toxic, nonbiodegradable organics and varied drastically in composition. EPA designated hazardous substances in the waste were removed very well. A synergistic enhancement of biological activity in the presence of activated carbon was observed.

Operation at over 25 days sludge age reduced the required carbon dose from more than 170 mg/liter to 120 mg/liter.

Activated carbon was regenerated from wasted PACT sludge in a multiple-hearth furnace. Carbon was regenerated at 80% yield with recovery of 63% of virgin carbon properties. Production rate and quality recovery were below expectations. Furnace performance was hurt by underdesigned filtration and solids conveying equipment which limited throughput and in-time.

Excluding depreciation, operating costs were equal to projections, and for secondary/tertiary treatment alone have averaged \$0.16/m³ (\$0.61/1,000 gal.). Including depreciation, costs have averaged \$0.22/m³ (\$0.82/1,000 gal.).

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

In November of 1976, Du Pont and EPA agreed on a cooperative program to obtain operating and cost data from the start-up and initial two years of full-scale operation for secondary/tertiary treatment facilities at a 150,000-m³/min. (40-MGD) industrial wastewater treatment plant (WWTP) using Du Pont's patented* PACT process. This presented a unique opportunity to obtain operating data from the large-scale use of this novel treatment technology. PACT is a

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*U.S. Patent Nos 4,069,148 and 3,904,518 combined treatment process in which powdered activated carbon is added directly to the aerator in a conventional activated sludge process.

The treatment facilities would be located at Du Pont's Chambers Works site at Deepwater, New Jersey and would provide primary and combined secondary/tertiary treatment for aqueous waste from the Chambers Works. Total investment for the WWTP was approximately $46,000,000.

The Chambers Works is a multiproducts chemical plant manufacturing "Freon" fluorocarbons; general organic intermediates; dyes and dye intermediates; petroleum additives; iso-cyanates and elastomeric products; general industrial chemicals; sulfuric acid; and miscellaneous other products. The wastewater is highly colored. Since most plant processes are batch, the wastewater periodically contains slug discharges or organics, which results in a highly variable organic load.

Chambers Works waste is strongly acidic. During primary treatment, the acid is neutralized with lime. The sludge formed is settled in primary clarifiers, filtered to give an approximately 50-percent-solid cake, and disposed of in an on-site, double-lined, secure landfill. Effluent from primary treatment has a pH of 6.0 to 8.0 and is the feed to the PACT process. Average composition of the PACT feed during 1978 and 1979 is presented in Table 1.

The PACT process was developed as a result of technical studies of alternative treatment procedures for Chambers Works wastewater. Results of the studies can be generalized by saying that a biological treatment process appeared most economical but could not consistently meet the BOD_5 limit, while physical-chemical treatment processes were expensive and failed to remove more than 60 percent of the BOD_5.

Physical-chemical methods generally failed to remove simple organic molecules, e.g., methanol and acetic acid, which were most easily biodegraded. Biological units failed to remove some complex organics, including those strongly coloring the wastes, and were plagued by periodic upsets due to variations in total organic load and/or surges of specific toxic compounds.

In an experiment, powdered activated carbon was added to a biological reactor. Results were so favorable that a program was established to pursue this new technology. A summary of typical operating data comparing a PACT unit with a conventional activated sludge unit is presented in Table 2. In addition to reductions in color, DOC, and BOD_5 removals, the spread of effluent values around the average was more narrow for the PACT unit.

The laboratory studies with Chambers Works wastewater demonstrated that, compared to a conventional activated sludge system at equal sludge age of 8 days, the PACT process with 160 mg/l carbon addition of one type carbon gave consistently high BOD_5 removal, increased DOC removal, increased color removal, eliminated foaming in the aerator, improved sludge settling and filtration properties, and protected the microorganisms from periodic shock loads of toxic compounds. There is a synergistic relationship between the bacteria and carbon in the PACT process such that more organics become biodegradable in the presence of carbon. In addition, the carbon provides an adsorption sink to minimize the effects of sudden changes in feed concentrations of organics, thereby decreasing the number and duration of excursions of effluent DOC concentrations.

Cost estimates for a PACT system versus a conventional activated sludge plant were within 10 percent of each other. The extra PACT investment for carbon handling and regeneration facilities was mostly offset by additional clarifier capacity and sludge disposal facilities needed for the activated sludge plant. Assuming a 75 percent regeneration yield for powdered carbon, operating costs for the PACT process were about 25 percent greater than for activated sludge alone. In effect, the PACT process at Chambers Works was expected to

Table 1. *Average Feed to PACT Treatment System*

Parameter	*Jan. 1978-Dec. 1979 24-month average*	*Design flowsheet*
Flow rate, m³/min.	*94.2 (24,900 gpm)*	*100 (26,400 gpm)*
Soluble BOD_5, mg/l	*171*	*280*
kg/day at avg. flow	*23,200 (51,000 lb/day)*	*40,300 (88,700 lb/day)*
DOC, mg/l	*170*	*205*
kg/day at avg. flow	*23,100 (50,800 lb/day)*	*29,500 (65,000 lb/day)*
Color, APHA	*1,530*	*1,000*
pH	*6.0-8.0*	*6.0-8.0*
TSS, mg/l	*37*	*30*

Table 2. *Typical Laboratory PACT Unit Performance* (October 1975 - April 1976)*

Parameter	*Feed*	*Treated Effluent*	
		PACT Unit	*Act. Sludge Unit*
Color, APHA units	*1690 (690)***	*310*	*1020*
DOC, mg/l	*171 (28)*	*26 (13)*	*57 (27)*
BOD_5	*300 (21)*	*23*	*38*
Operating Conditions			
Sludge Age, days		*8.0*	*8.3*
Carbon Dose, mg/l		*160*	*0*
Temperature, °C		*15-24*	*15-24*
Aerator Hydraulic Residence Time, hours		*6.1*	*5.7*

**Values are average of 100 daily data points except for BOD_5 which are averages of 36 data points.*
***(Standard deviation).*

provide tertiary treatment quality effluent at a cost slightly higher than that for secondary treatment alone.

Chambers Works Wastewater Treatment Plant

A flow diagram of the plant showing equipment arrangement is depicted in Figure 1. Flow through the plant is by gravity. PACT treatment starts at the flow splitter where neutralized primary effluent enters from four primary clarifiers. A slurry of regenerated plus virgin makeup carbon is added to the wastewater. Slurry flow rate is controlled to maintain the desired carbon dosage.

Recycle activated sludge (RAS) is combined with the primary effluent and fed to the aerators. Each aerator provides about 7 hours hydraulic residence time. Static mixers in each aerator provide the mixing necessary to suspend the PACT sludge as well as oxygen transfer. Air is supplied through headers extending across the center of the tank along the floor.

Bottom take-off lines from each aerator combine in a common line to the clarifier feed flowsplitter. Mixed liquor is fed to a center well of each of two secondary clarifiers from which it overflows into a flocculating zone. Treated wastewater is discharged to a final settling basin prior to discharge to the Delaware River estuary.

Solids are wasted from the liquid train via a thickener. Either aerator effluent or RAS may be fed to this carbon thickener. Supernatant from the

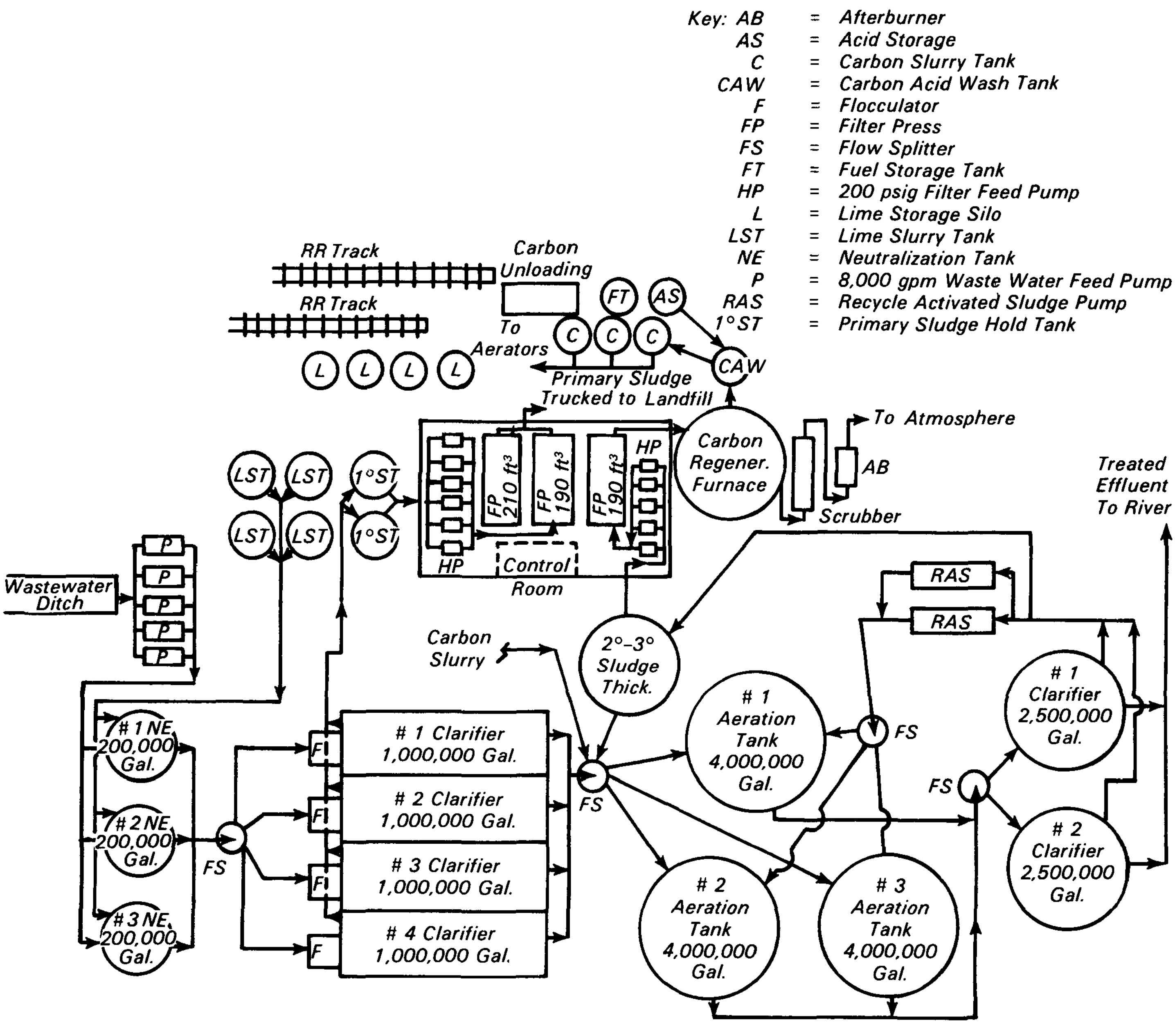

Figure 1. *Flow diagram of Chambers Works wastewater treatment plant.*

thickener is returned to the aerators. Approximately 10 percent slurry from the thickener enters a filter feed tank, from which it is fed to the PACT filter press. The horizontal filter press is an automatic unit containing 112 recessed chambers. Filter cake from the press drops into a bunker from which a multi-stage conveyor system moves it to the top of the regeneration furnace.

Sludge drops through gate-lock feeders onto the center of the top (#1) hearth of the multiple-hearth regeneration furnace. There are five hearths in the furnace. Hot gases from an external fuel oil-fired burner are fed into the bottom (#4 and #5) hearths. The furnace has a rotating centershaft with two rabble arms on each hearth. Solids are raked to drop holes at the outer edges of hearths #1 and #3. On #2 and #4 they are moved to the center of the hearth, where there is an annular hole around the center shaft through which the solids drop. The furnace is designed to reduce upward gas velocity and thereby minimize entrainment of carbon particles.

The principle of operation is that water is evaporated from the sludge on hearths #1 and #2 at gas temperatures from 480° to 700°C. On hearth #3 the biological solids and adsorbed organics are burned off by 750° to 870°C gas. On the bottom two hearths, at gas temperatures from 870° to 1,020°C, the powdered carbon is reactivated in the presence of water vapor.

Incandescent powdered carbon is rabbled through a grate at the outer edge of the #5 hearth into a quench tank. Sufficient water is fed to the tank to give a 5-percent slurry concentration. The slurry is continuously withdrawn and fed to a continuous stirred HCl acid wash tank. Acidified slurry overflows into a water dilution jet. Diluted slurry at about 1-percent solids concentration feeds a carbon thickener tank. A 10 to 12 wt.% slurry discharges from the bottom of this tank to one of three carbon slurry storage tanks. The storage tanks hold slurries of regenerated and make-up virgin carbon for feed to the aerators. Virgin carbon usage is 4,500,000 to 2,700,000 kg/year (10 MM to 6 MM lbs/year). The plant tank farm also includes tankage for H_2PO_4 nutrient, fuel oil, and HCl storage.

Plant Start-Up

The start-up procedure called for an initial charge of 60,000 kg (4,000 mg/liter) of powdered activated carbon to one of the aerators. The aerator would then be seeded with 2,000 mg/liter of biological solids. Concurrently, primary effluent would be fed through the aerator and one clarifier at one-half the normal operating rate. Wastewater flow would then be gradually increased to full rate. During this time, a dose of 80 mg/liter of virgin activated carbon would be continuously added to the feed. When the first aerator was at full rate and the biological system fully established, one-half the aerator MLSS was to be transferred to the second aerator. Flow to both aerators would be set at one-half normal rates and then gradually increased to full rate. The same procedure would then be used to start the third aerator.

During the seeding period (November 19, 1976, to December 15, 1976), a total of 42,000 kg dry weight of biological solids were trucked to Chambers Works and pumped into the aerators. Biological solids were obtained from two New Jersey waste treatment plants. Most came from the Gloucester Regional Treatment Plant; the remainder came from American Cyanamid's Bound Brook plant. Aerator temperature during this time varied from 10° to 21°C. Foaming in the aerators, which had been a problem during hydraulic testing, stopped as soon as the powdered carbon was added to the aerators.

The liquid train was capable of full-flow operation in February 1977; however, there were delays in getting the solids train up to normal production rate, so the plant was limited in the amount of solids which could be wasted. To minimize the buildup of solids in the liquid train, flow to the PACT process was restricted until June 1977. Full flow had to be accepted at that time to meet the NPDES permit deadline for full wastewater treatment. Start-up of the solids train commenced in Januray 1977. It took over 13 months, until February 1978, before all portions were running satisfactorily.

Full-Scale Operation - Liquid Train

In the first 30 months of full-scale operation, the PACT process has exceeded expectations in terms of BOD and color removal. Effluent DOC concentrations have been lower than forecast, and the percent removal has almost equalled forecast. Average performance for 24 months (Jan. 1978 - Dec. 1979) is summarized in Table 3.

There has been a narrow distribution of effluent concentration of critical waste parameters vs. wide variations in feed concentrations. This performance has been achieved even though the wastewater is more highly colored and contains a higher ratio of nonbiodegradable organics than expected. Normally nonbiodegradable or very slow degradable materials are being removed in the presence of the activated carbon. Even more important, in terms of meeting NPDES permit limits at the ultimate Chambers Works river outfall, performance has been very consistent.

The PACT system has been very effective in removing EPA-designated organic priority pollutants (Table 4). Base-neutral compounds are not as well removed as volatile organics and acid extractable compounds. Some removal of metals occurs across PACT, but the process is not designed for metals treatment.

A major reason for selection of the PACT process was the protection that powdered carbon afforded the biosystem from toxic upsets caused by shock loads of organic compounds. Because of the variety and large number of batch production operations at Chambers Works, it is not uncommon for the WWTP to receive 10,000-kg slugs of various organics over a 2- to 4-hour period. The biosystem has handled, with no ill effects, known spills of 23,000 kg of an aromatic diamine and 14,000 kg of a toluidine.

During a single day the inlet DOC concentration will normally vary by a factor of two, although on rare occasions, it has varied by as much as a factor of five. The daily average DOC load is usually within 30 percent of the load of the previous day. In 30 months of full-scale operation there have been only three instances when an upset has seriously diminished PACT system performance. In these cases, DOC removal dropped to the 50-60 percent range for up to 3 days and was below normal for up to 20 days. BOD and color removals dropped correspondingly. However, in no case has there been anything close to a complete kill of the bacteria.

The first upset occurred in July 1977, and was partially attributed to a weakening of the biosystem at high temperature. Evasive measures which are now taken routinely at the first sign of upset had not yet been implemented. The second upset occurred in October 1978. Identified abnormal conditions were: high carryover of solids from primary treatment; lower quality activated carbon in the aeration tanks; and rapid, seasonal temperature change in the aera-

Table 3. PACT System Performance, 1978 & 1979

	24-month avg.	Design
Flow	94.2 m^3/min (24,900 gpm)	100 m^3/min (26,400 gpm)
Inlet Soluble BOD_5, mg/l	171 (51,000 lb/day)	280 (88,700 lb/day)
Effluent Soluble BOD_5, mg/l	6.7 (2,000 lb/day)	21 (6,700 lb/day)
% Removal	96	93
Inlet DOC, mg/l	170 (50,800 lb/day)	205 (6,500 lb/day)
Effluent DOC, mg/l	31.2	35
% Removal	82	83
Inlet Color, APHA	1530	1000
Effluent Color, APHA	483	500
% Removal	66	50

tion tanks. The third upset, in January 1979, coincided with a high level of cyanide in the aerators. Although the exact cyanide level in the MLSS could not be determined, subsequent laboratory studies have shown that cyanide ion at concentrations above 0.1 percent in the MLSS can cause severe inhibition of even the PACT system.

Since start-up, the WWTP has operated at higher sludge age and lower carbon dose than that for which it was designed. The plant was forced into this operating mode by capacity problems in the solids train. This operating mode has limited the wastage rate of MLSS from the aeration tanks. As a result, the aerators have operated at monthly average MLSS levels from 18,000 to 30,000 mg/liter. Average sludge age has ranged from 20 to 60 days. Solids not wasted via the solids train must leave the system as TSS in secondary clarifier overflow. This has resulted in an average effluent TSS level of 103 mg/liter vs. a design value of 30 mg/liter.

Because of the high solids load throughout the system, the secondary clarifiers have been badly overloaded since start-up. Several process and mechanical modifications have not solved the basic problem—the solids have to go somewhere. However, the expected solids settling rate (with PACT MLSS) has been seen in the clarifiers.

Effluent from the WWTP is mixed with uncontaminated cooling water in a settling basin before being discharged to the river. Overflow PACT solids settle here. They are ultimately dredged, returned into wastewater which is fed to primary treatment, and removed with the primary solids. This results in higher-than-forecast carbon losses, as this carbon is unavailable for regeneration.

Because of much better aeration tank performance at high sludge age, the plant has been able to operate at an average carbon dose of 120 mg/liter and still meet all required effluent quality standards. As the design carbon dose was 180 mg/liter, net carbon costs have been no higher than design projection. Two types of virgin carbon are used, Hydrocarco C (HD-C) and Nuchar SA (SA). Although other carbons have been tested, these are the only two of satisfactory quality which are available in sufficient quantity for use. In the 24 months of operation activated carbon feed has been 48% SA, 14% HD-C, 3% test carbons, and 35% regenerated carbon. Nuchar SA has been the most effective in treating Chambers Works waste; however, it is also the most expensive.

As expected, biological activity has been a function of aerator temperature. The carbon dose is increased in the winter to compensate for lower biological activity at low temperature. Despite the July 1977 upset at 38.4°C, the plant operated well at daily average aerator temperatures of up to 38.8°C in subsequent summers. Up to these temperatures, biosystem performance appears to steadily improve. Since there are other factors affecting WWTP operation, only a general trend in the relationship among temperature, activity, and carbon dose has been determined.

The most important repetitive decision in PACT operation is setting carbon dose. This dose must be sufficient to raise the level of biological treatment to meet a specified effluent quality. Operating limits on effluent quality are set to assure that, after WWTP effluent is mixed with 1.5 times its volume of noncontact cooling water in the settling basin, the combined effluent meets NPDES permit limits. In practice, this means that the carbon dose is adjusted based on the level of DOC and color in the plant effluent. When limits for these more refractory parameters are met, the BOD concentration is always well below the allowed limit. The budgeted carbon dose for 1980 is 114 mg/liter, of which 50 percent is to be regenerated carbon.

In theory, carbon dose should be adjusted proportionally to the inlet concentrations of color and/or DOC. However, as the composition of Chambers Works waste varies from day to day, so does the ease or difficulty of treatment. At the same inlet concentrations there can be drastic differences in the percent removals achieved at a given carbon dose. Since the plant has operated at sludge ages of over 20 days, it is impossible to drastically change the activated carbon content of the MLSS in a few days. Thus, despite a short-term drop in inlet DOC or color, carbon dose still must be kept high enough to maintain an adequate concentration in the MLSS. The WWTP has generally been operated to maintain the several-day average of DOC removal above 80 percent.

There are two other constraints on carbon dose that are controlling at times. The higher the product of carbon dose and quality in the MLSS, the more resistant a PACT plant is to upsets. In effect, a high activated carbon level in the aeration tanks is insurance against an upset of unpredictable magnitude which might occur at any time. Another constraint on carbon dose has been PACT sludge filterability. Carbon in the sludge drastically increases filterability. Advantage was taken of this in the design of the WWTP. Filtration capacity installed was less than would have been required for a similar capacity activated sludge plant; however, carbon dosages assumed during design were in the range of 130 to 180 mg/liter. By taking

Table 4. *Priority Pollutant Removals Across PACT System**

Compound	*Feed*	*PACT Effluent*	*Removal (%)*
	Concentration in μg/liter (ppb)		
Volatile Organics			
Benzene	*105*	*0.9*	*98*
Carbon Tetrachloride	*94*	*1.4*	*95*
Chlorobenzene	*1720*	*30*	*98*
Chloroethane	*280*	*12*	*94*
Chloroform	*201*	*21*	*81*
Ethylbenzene	*41*	*1.7*	*94*
Methyl Chloride	*1770*	*Nil*	*99*
Tetrachloroethylene	*24*	*1.7*	*93*
Toluene	*519*	*1.7*	*99*
1,1,1-Trichloroethane	*13*	*0.6*	*89*
Trichloroethylene	*41*	*1.9*	*94*
Trichlorofluoromethane	*155*	*3.0*	*95*
Base-Neutral Extractables			
1,2-Dichlorobenzene	*259*	*120*	*44*
2,4-Dinitrotoluene	*1900*	*243*	*65*
2,6-Dinitrotoluene	*1640*	*575*	*64*
Nitrobenzene	*454*	*2*	*99*
1,2,4-Trichlorobenzene	*523*	*169*	*66*
Acid Extractables			
2-Chlorophenol	*11*	*1.6*	*95*
2,4-Dinitrophenol	*161*	*5.0*	*98*
4-Nitrophenol	*1020*	*10*	*97*
Phenol	*489*	*38*	*94*
Metals			
Antimony	*20*	*10*	*50*
Arsenic	*19*	*21*	*Nil*
Beryllium	*1.4*	*1.0*	*29*
Cadmium	*5.6*	*5.4*	*4*
Chromium	*26*	*15*	*42*
Copper	*72*	*75*	*Nil*
Lead	*112*	*54*	*52*
Mercury	*.02*	*.01*	*50*
Nickel	*77*	*59*	*23*
Selenium	*29*	*23*	*21*
Zinc	*602*	*360*	*40*

**Values are averages of data which show significant day-to-day variations in removals. Results were obtained by GC/MS analyses of plant samples and are subject to analytical error.*

advantage of operation at long sludge age, the WWTP has operated successfully at carbon doses as low as 50 mg/liter, particularly at warmer temperatures and lower DOC loads. Sustained operation at less than 100 mg/liter carbon dose lowers the activated carbon content of the MLSS below 50 percent. At this point, filterability of PACT sludge drops drastically. In the summers of 1978 and 1979, carbon dose often had to be held above that strictly necessary for DOC or color removal in order to sustain a minimum acceptable filtration rate in the PACT filter press.

The plant has evolved procedures for evasive actions in case an imminent upset is suspected. In order of priority, the procedures are to reduce wastewater flow, to increase air flow to the aerators, and to raise carbon dose by 100 mg/liter. Procedures now call for an automatic decrease in flow if inlet DOC concentration doubles within one to two hours; an increase in air flows if a shock load of inhibitory material is apparent; and, an automatic 100 ppm increase in carbon dose if effluent DOC rises above 50 mg/liter.

Full-Scale Operation - Solids Train

The most significant solids train operating result is the demonstration that powdered activated carbon can be regenerated from PACT sludge, at good yield and reasonable quality, in a countercurrent multiple-hearth regeneration furnace. With the aid of a post-regeneration acid wash, the carbon can be regenerated several times with no build-up of ash or other impurities which could harm performance.

Overall performance of the solids train has been below design because of serious capacity limitations in the sludge-conveying system and the PACT filter press (the latter not withstanding the relatively good filtration properties of PACT sludge vs. normal activated sludge). Because of these capacity problems, operation of the regeneration furnace has so far approximated only a break-even proposition. However, there is no assurance that the alternative, using carbon on a one-through "throw away" basis, could be cost-effective for very long, even at low dose operation.

From February 1978 through December 1979, the regeneration furnace operated at 55 percent intime (intime being defined as sludge being fed to the furnace). This period includes major outages of 5-1/2 and 7 weeks each to rebuild furnace hearths. Hearth life has been shortened by inability to maintain a constant furnace feed. Feed interruptions allow hearth temperatures to rise to excessive levels and cause rates of temperature change in excess of the recommended 40°C/hour maximum. Exclusive of hearth rebuilding and one shutdown for a rabble arm repair, furnace intime has averaged 66 percent. However, half of the downtime has been caused by failures of the feed system rather than the furnace itself. While operating, the furnace has produced 4,100,000 kg of regenerated carbon with an estimated quality recovery of 63 percent. The yield based on carbon fed to the furnace is estimated at 80 percent.

There have been no problems with the acid-washing system for regenerated carbon slurry. After acid-washing, the average ash and volatile levels of the carbon have been 18 percent and 9 percent, respectively (virgin carbon as purchased will contain from 4 to 30 percent ash and 10 to 20 percent volatiles). Average feed rate during intime has been 2,240 kg/hour wet sludge. A summary of furnace performance is presented in Table 5. The heat load on the furnace is significantly less than design value because of the higher percent solids achieved in filtration. This has contributed to temperature control problems as the burner is oversized for these operating conditions.

Performance of the conveyors has been poor. Operating utility of the conveyor system itself has been approximately 80 percent. The most important factor affecting utility is mechanical wear. The carbon coke is erosive and seriously wears the metal in the drag flight conveyors. Operating strategy has been to upgrade the equipment mechanically as much as possible. There are now parallel units at two stages in the conveyor system. Parallel units at two more stages were scheduled for installation early in 1980. With the conveyors running well, furnace capacity is limited by plugs of the gatelock feeders on top of the furnace. Plugging is a function of filter-cake quality.

In retrospect, it appears that the filters should have been located above the regeneration furnace; or the filter and furnace should have been located horizontally far enough apart that an inclined belt conveyor could have been used to transport sludge. Although not devoid of problems, PACT solids move very well in slurry form when using proper piping, valves, and pumps. It would have been much easier to pump slurry 15 meters to a filtration unit than to drag filter cake the same distance.

Intime of the PACT filter press has averaged about 85 percent since January 1978. The main causes of lost time have been 16-hour high-pressure water washings every week to 10 days, numerous shutdowns for periodic replacement of press cloths, gaskets, etc., and outages of high-pressure feed pump(s). The latter problem has been somewhat ameliorated by the use of one triplex, higher capacity piston pump to replace the four parallel originally installed pumps.

The most serious problem with the press has been long cycle times. They vary from 1.5 to 7 hours, depending on sludge composition and filter-cloth condition. At carbon dose over 100 mg/l, cycles average between 2 and 3 hours; at lower carbon dose they average about 4 hours. Even though laboratory-measured sludge filtration properties are close to design values, press cycle time is still longer than expected. Calculations of cycle time were simply overly optimistic. Also, because of the low dose, long sludge age mode of operation, carbon content of the PACT sludge has never been as high as forecast.

Filter-cake quality in terms of percent solids has exceeded design; however, there is a surprising variation in cake quality within a very narrow range of solids concentration. Depending on composition of the MLSS, a greater-than-40-percent-solids cake can either be an easily handled, friable cake or a material of the consistency of bubble gum and very difficult to convey.

The sludge thickener has worked well and consistently delivers a 7-10 wt.% slurry for feed to the PACT filter press. Because the thickener has worked as well as it has, sludge can be wasted directly from the aerators instead of from the more concentrated RAS stream. Sludge will go "stale" and be hard to filter if it is held in the thickener during a filter outage.

Precoat is used before each press cycle. Studies have demonstrated its need, but there have been no major improvements in press performance from varying precoat types and quantity. An ash-free type material, like cellulose, is needed because it is burned in the furnace. Tests have recently been made of direct addition of a polymer to the sludge to improve filterability. No major improvement has been seen to date; however, further work is planned. Frequency of filter-press cleaning varies depending on sludge condition. A thorough cleaning requires over 16 hours. Approximately once a year it has been necessary to completely re-dress the filter press. This costs $13,000 and takes 2 weeks. Underscreens cost $56,000 and may need replacement every 2 years.

Since Januray 1978, operating strategy has been to run the solids train at as high a rate as possible. Generally this has not been enough to equal the rate of solids added to the system, and the liquid train periodically purges itself via an overflow of TSS from the secondary clarifiers. Several steps have been taken to improve solids train production.

To maintain sludge wastage from the aerators when the regeneration furnace is out of service, filtered sludge is dumped to a payload container and

Table 5. *Regeneration Furnace Performance*

	Time Period			
	Feb. '78 thru Dec. '79	*June '79*	*March '78*	*Design Values*
Reg. Carbon Produced, kg/day	*5,860*	*7,000*	*9,600*	*18,200*
Kg Reg. Carbon/ kg dry feed	*.40*	*.50*	*.46*	*.53*
Carbon Yield, %	*80*	*Not Available*	*Not Available*	*70*
Est. Quality Recovery, %	*63*	*70*	*63*	*75*
Reg. Carbon, Iodine Number	*475*	*537*	*487*	*560*
*Reg. Carbon, % Volatiles**	*8.5*	*8.6*	*7.2*	*8*
Reg. Carbon, % Ash	*18.4*	*16.7*	*15.4*	*15*
Furnace in Time, %	*58*	*69*	*79*	*90*
Wet Sludge Feed Rate While Operating, kg/hr.	*2,240*	*1,940*	*2,440*	*4,190*
Sludge Feed, % Solids	*44*	*44*	*44*	*38*
Dry Solids Fed, kg/day	*14,900*	*13,900*	*20,800*	*34,300*
Regenerated Carbon Produced While Operating, kg/hr.	*443*	*421*	*506*	*1,770*

****Volatiles equal weight loss when carbon is heated to 950°C for 5 minutes at a controlled rate of temperature rise with minimum exposure to air.***

hauled to a storage area for future carbon recovery. An inventory of sludge is vital to maintaining feed to the furnace during filter-press outages. Current operating strategy calls for keeping some stored sludge available at all times.

Furnace operating options are limited because of a strong interdependence among operating conditions. Operating instructions specify an acceptable temperature range for each of the five hearths. Actions which bring the temperature of one hearth into range can drive another hearth's temperature out of limits. Therefore, the furnace operator does not have complete control over the hearth temperature profile. The profile is also very dependent on the sludge feed rate, which is a strong function of filter-cake quality. Other variables being constant, laboratory studies have shown that quality is generally obtained at the expense of yield and that better quality is achieved at higher temperature; therefore, the tendency now is to try to operate the upper hearths on the high side of the allowable temperature range.

The furnace must operate under reducing conditions with water vapor present to regenerate the carbon. In lieu of direct addition of steam, a portion of the 100-percent relative humidity off-gas from the scrubbing system is recycled back to the combustion chamber. It is now felt that higher water concentrations than are presently obtainable are needed to improve the quality of regenerated carbon. Facilities for direct steam addition have been installed, and tests are scheduled in 1980. A problem with this change, and furnace operation in general, is insuring that explosive CO and H_2 mixtures do not develop in the furnace from the water gas reaction; therefore, a continuing program of gas analyses is maintained. While there is a reassuring background of years of industrial operation of multiple-hearth furnaces to regenerate granular carbon, the fact that this system is treating powdered carbon is reason for caution.

Operating Costs

It cost approximately $16,500,000 a year to operate the Chambers Works wastewater treatment plant in 1978 and 1979. Of this, approximately $10,000,000, or 65 percent, is the estimated cost of PACT secondary/tertiary treatment. Primary treatment costs include over $1,500,000 to purchase the lime needed for acid neutralization. Annual depreciation charges of $4,000,000 on a book investment of over $45,000,000 make up 25 percent of the annual operating costs.

Average annual operating costs for 1978 and 1979 are shown in Table 6. As this study deals with PACT treatment only, each individual item of cost has been proportioned as accurately as possible between primary and secondary/tertiary treatment.

At the average plant flow of 94 m^3/min. (24,900 gpm) costs, including depreciation, have averaged $.33/$m^3$ ($1.27/1,000 gal.) for total treatment, or $0.22/$m^3$ ($0.82/1,000 gal.) for PACT treatment only. Because many costs are independent of load, unit costs would drop significantly if the plant were operated closer to capacity. Many treatment facilities report costs exclusive of depreciation charges. Ignoring depreciation, the costs for PACT treatment have averaged $0.16/$m^3$ ($.61/1,000 gal.).

In attempting to extrapolate these costs to other waste treatment operations, it must be realized that operating and mechanical personnel involved with the Chambers Works plant are relatively well paid. Their average earnings approach $10 an hour plus an additional 40 percent for fringe benefits. A rough estimate of the current replacement value for the total treatment plant is $60,000,000; the PACT process share of this updated investment is about 65 percent. Direct maintenance costs, including all overheads, have run about 3.7 percent of total updated investment. Maintenance costs are forecast to decrease significantly in 1980 as a result of mechanical improvements over the past two years.

The plant is currently staffed with 29 operators, 4 salaried shift supervisors, 2 day supervisors, plus 6 other management and technical people. There are approximately 30 mechanics, electri-

Table 6. *Wastewater Treatment Plant Operating Costs*

	Average Annual Costs in Thousands*		
Cost Items	*Primary Treatment*	*PACT Secondary/ Tertiary Treatment*	*Total*
Lime	*$ 1,540*	*$ —*	*$ 1,540*
Other Raw Materials-Primary	*150*	*—*	*150*
Activated Carbon	*—*	*3,010*	*3,010*
Polymer, PACT	*—*	*190*	*190*
Filter Aid, PACT	*—*	*20*	*20*
Acid for Carbon Washing-PACT	*—*	*20*	*20*
Phosphoric Acid-PACT	*—*	*30*	*30*
Total Raw Materials	*$ 1,690*	*$ 3,270*	*$ 4,960*
Primary Treatment-Utilities	*460*	*—*	*460*
PACT-Steam	*—*	*70*	*70*
PACT-Fuel Oil	*—*	*170*	*170*
PACT-Electricity	*—*	*610*	*610*
PACT-Other Utilities	*—*	*20*	*20*
Total Utilities	*460*	*870*	*1,330*
Operating Labor	*420*	*420*	*840*
Mechanical Labor, Materials	*560*	*1,670*	*2,230*
Salary Personnel	*230*	*380*	*610*
Depreciation	*1,430*	*2,650*	*4,080*
Overheads	*340*	*770*	*1,110*
Computer	*50*	*60*	*110*
Miscellaneous Supplies	*—*	*270*	*270*
Laboratory Support	*—*	*160*	*160*
Other Services	*—*	*150*	*150*
*Other Primary Treatment Expenses***	*670*	*—*	*670*
Total Other Costs	*3,700*	*6,530*	*10,230*
Total Plant Costs	*$ 5,850*	*$10,670*	*$16,520*

**Average for Years 1978 and 1979.*
***Including Landfill Charges.*

cians, and instrument technicians currently assigned to the plant. Both operating and mechanical staffs are forecast to drop by 15 to 20 percent in the next year.

Harry W. Heath, Jr., is with E. I. du Pont de Nemours & Company, Inc., Chambers Works, Deepwater, NJ 08023.
***John E. Matthews** is the EPA Project Officer (see below).*
The complete report, entitled "Full-Scale Demonstration of Industrial Wastewater Treatment Utilizing Du Pont's PACT® Process," (Order No. PB 81-248 122; Cost: $14.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

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