ENVIRONMENTAL PROTECTION AGENCY

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REPORT ON

TOTAL ORGANIC CARBON REMOVAL FROM MUNICIPAL & INDUSTRIAL WASTEWATER

PREPARED BY

DIVISION OF FIELD INVESTIGATIONS - DENVER CENTER

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CLEAN WATER

ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY OFFICE

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MUNICIPAL AND INDUSTRIAL WASTEWATER

by

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Abstract

Physical-chemical treatment processes provide overall removal of organic waste matter of more than 95 percent on raw domestic or domestic-industrial wastewaters despite variations in organic loadings and the presence of toxic chemicals.

The annual operating cost for physical-chemical treatment of raw wastewaters is equal to or less than the cost of conventional biological treatment.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

This paper summarizes the results of studies undertaken to determine methods of removing total organic carbon (TOC) from municipal and industrial wastewaters. A conventional biological treatment facility will provide, at best, approximately 90 percent removal of suspended solids and biochemical oxygen demand (BOD). Although the effluent from these plants meets current state water quality regulations, more stringent demands are being instigated to remove a greater amount of the contaminants, such as phosphate, nitrate and total organic carbon, from wastewater before it is discharged into the receiving waters.

Two possibilities are available to remove organic contaminants from wastewater. These are to provide tertiary treatment to the effluent from the secondary biological treatment facility, thereby significantly increasing the cost of treatment, or to provide treatment of raw wastewater by a physical-chemical treatment process. The physical-chemical process includes chemical clarification, filtration, and adsorption (1).[1/]

Granular activated carbon adsorption has proven to be one of the most successful and economical advanced waste treatment processes and is in full-scale operation in municipal water, municipal wastewater and industrial wastewater treatment facilities (2) (3) (4) (5) (6). When used in conjunction with chemical precipitation and filtration, 95 percent or greater removal of TOC, BOD, chemical oxygen demand (COD), total phosphates and suspended solids and 78 percent of total nitrogen

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[1/] Numbers in parentheses refer to bibliography.

can be removed from raw wastewater (7). In addition, the carbon adsorption process, as a secondary treatment step, has the following potential advantages over biological processes (3).

1. The land requirement can be as much as 10 times greater for a biological treatment facility.
2. The capital costs are higher for a conventional biological process.
3. Shock loadings, toxic wastes and low temperatures have less effect on carbon adsorption.
4. Operating conditions can be easily changed in a carbon adsorption system to meet varying influent quality flow changes.
5. Odor problems are reduced with the carbon adsorption process.
6. The volume of sludge produced is greater in a conventional biological process.

SUMMARY

A review of literature shows that efficient removal of TOC from secondary effluents and raw wastewater, either domestic or domestic-industrial in origin, is practicable. Physical-chemical treatment facilities, consisting of chemical clarification, filtration and carbon adsorption, can remove more than 95 percent of the TOC from either secondary effluents or raw wastewaters.

The physical-chemical treatment process should be applied directly to raw wastewaters, as this provides the best quality effluent at the lowest cost. Studies have shown that for a 10 million gallon per day wastewater flow, the capital and annual operating costs for a physical-chemical facility are less than for an activated sludge facility. Estimates of annual operating cost for physical-chemical treatment vary from $0.03 to $0.11 per 1,000 gallons of wastewater treated, depending on size and design efficiency of the treatment facility.

Although there has been only a small number of studies conducted on removal of organic contaminants from industrial wastewaters, the physical-chemical treatment process should provide an excellent quality effluent, as this process is not affected by shock loadings, pH fluctuations, changes in temperature or toxic substances.

REVIEW OF LITERATURE

Processes for increased removal of organics from domestic and industrial wastewater streams are in varying stages of development. These processes include:

1. Activated Carbon
2. Adsorbent Resins
3. Oxidation Processes

ACTIVATED CARBON

Over the last few years, many lab and field evaluation tests have confirmed the technical and economic feasibility of treating raw wastewater and secondary effluent with activated carbon to remove organics. This has resulted in the application of a physical-chemical process to treat wastewater. This process utilizes: (a) chemical clarification, either lime precipitation or metallic salts ($FeCl_3$ or alum), and filtration to remove colloidal substances, and (b) adsorption of organics by activated carbon (1) (7).

The following paragraphs summarize either completed or on-going work utilizing carbon adsorption practices.

A granular activated carbon wastewater treatment process has been demonstrated at the Cuyahoga County wastewater treatment facility in Rocky River, Ohio (3). This carbon adsorption process treated chemically clarified raw sewage and produced an effluent which was better than effluents normally obtained from conventional biological secondary treatment facilities. Data from the Rocky River study are summarized in Table 1 (8). The clarification/adsorption process removed 75 percent of the TOC, 81 percent of the COD and 93 percent of the BOD contained in the raw sewage.

TABLE 1

ROCKY RIVER WASTE TREATMENT PLANT CLARIFICATION/CARBON PROCESS[1/]

	Raw Water	Clarified Water	Carbon Column Effluent Carbon Contact Time, Minutes 4.7	14	23.4	32.6	Percent Removed
Suspended Solids mg/l	107	65	31	13	15	7	93.3
BOD, mg/l	118	57	27	21	11	8	93.3
COD, mg/l	235	177	117	67	50	44	81.3
TOC, mg/l	52	53	33	18	15	13	75

1/ Data from Rizzo, J. L., and R. E. Schade, "Secondary Treatment with Granular Activated Carbon." Water and Sewage Works, August 1969. (8)

TABLE 2

TREATMENT OF PRIMARY EFFLUENT BY POWDERED CARBON, LEBANON, OHIO[1/]

Run	Carbon (mg/l)	Flow (gpm)	TOC Primary Effluent (mg/l)	Powdered Carbon Effluent (mg/l)	Percent Removal
3	200	5	69.0	10.2	85.2
5	200	5	41.7	3.7	91.1
6	200	5	46.3	4.1	91.1
7	200	5	48.4	6.7	86.1
9	300	5	67.1	11.0	83.6

1/ Data from Masse, Arthur N., "Removal of Organics by Activated Carbon." Robert A. Taft Water Research Laboratory, August 1968 (mimeo) (3).

A 7200 gallon per day physical-chemical pilot plant was field tested for one year at the Ewing-Lawrence Sewage Authority wastewater treatment facility near Trenton, New Jersey. The wastewater is comprised of approximately 25 percent industrial wastes and 75 percent domestic wastes (1). This pilot plant consistently provided greater than 95 percent removal of TOC and BOD despite the variations in waste strengths and composition. The effluent contained 0.5 milligrams per liter (mg/l) or less of TOC compared to about 30 mg/l for the same wastewater treated conventionally by a trickling filter. The phosphate and nitrate removal rate was 90 percent or greater during the study. In addition, the study showed that 340 lbs. of activated carbon will remove approximately 45 lbs. of TOC (1).

The 10 gallon per minute powdered activated carbon pilot plant at Lebanon, Ohio, waste treatment facility operates on primary effluent (3). TOC removal varied from 83 to 91 percent and is summarized in Table 2. The final effluent from this carbon adsorption process was always less turbid and lower in organic carbon than the effluent produced by the activated sludge plant operating on the same primary-treated wastewater (3). Activated sludge normally does not reduce the organic carbon concentration below 20 mg/l (9).

The Lebanon facility has also been tested using granular activated carbon (10). The lime clarification-carbon adsorption system operates at steady flow conditions treating primary effluent. This primary effluent is fed to the lime clarification process for removal of suspended matter and phosphates. The wastewater then passes through dual-media filters to the carbon contactors for removal of additional soluble organics. The clarification process by itself removed 76 percent of the TOC. The overall removal of BOD, TOC, and COD by this process was 87 percent. Table 3 summarizes the organic removal from the system. The authors (10) suggest that the TOC removal rate may be lower than what could be expected since the carbon columns were not designed for efficient backwashing. This inability to efficiently backwash the carbon columns could reduce the amount of activated carbon available for organic adsorption.

Physical-chemical treatment of the District of Columbia raw wastewater in a 100,000 gpd pilot plant which consists of two-stage lime precipitation, filtration, pH control, ion exchange and carbon adsorption provided 98 percent, 95 percent, and 78 percent removal of phosphorus, organics and total nitrogen, respectively, for the 6-month operating period (7). The lime treatment phase of this process alone removed approximately 96 percent of the phosphorus and 80 percent of the BOD, TOC and COD. The final effluent from the carbon adsorption beds contained average residual organics of 5 mg/l BOD, 6 mg/l TOC and 13 mg/l COD. Tables 4 and 5 summarize the removal rates of TOC and BOD in each step of this physical-chemical process.

Personnel of the Robert A. Taft Sanitary Engineering Center conducted pilot-scale studies of adsorption on granular carbon from four different secondary effluents derived from domestic and industrial wastes (2). These waste sources had been treated by either activated sludge or trickling filters.

The study determined removal of TOC, turbidity and phosphate from these secondary effluents by either filtration and carbon adsorption or chemical clarification, filtration and carbon adsorption. Table 6

TABLE 3

TREATMENT OF PRIMARY EFFLUENT BY GRANULAR CARBON 1/
LEBANON, OHIO

	BOD (mg/l)	TOC (mg/l)	COD (mg/l)	SS (mg/l)	P (mg/l)	Turbidity (JTU)
Primary Effluent	76	76	192	85	9	55
Lime Clarification and Dual Media Filtration Effluent	25	26	67	10	1	2
Granular Carbon Effluent	10	11	27	1	1	1
Overall Removal (%)	86.8	85.5	86.9	98.7	88.9	98.2

Average ratios determined from study

$\frac{BOD}{TOC} = 1.08$ $\frac{COD}{TOC} = 3.13$

1/ Data from Villiers, R. V., E. L. Berg, C. A. Brunner, and A. N. Masse, "Treatment of Primary Effluent by Lime Clarification and Granular Carbon." Advanced Waste Treatment Research Laboratory, May 1970. (10)

TABLE 4
TOC REMOVAL[1/]

Month (1970)	Influent (mg/l)	Clarification Residual (mg/l)	Clarification Percent Removal[3/]	Filtration Residual (mg/l)	Filtration Percent Removal[3/]	Ion Exchange[2/] Residual (mg/l)	Ion Exchange[2/] Percent Removal[3/]	Adsorption Residual (mg/l)	Adsorption Percent Removal[3/]
March	118	25.5	78	20.1	83	14.9	87	3.7	97
April	102	22.8	77	19.9	81	14.8	85	4.9	95
May	114	18.8	84	16.8	85	13.5	88	8.1	93
June	85	18.1	79	18.5	78	14.5	83	8.3	91
July	78	17.6	78	17.3	78	11.8	82	5.2	93
August	96	17.5	82	18.4	81	6.1	93[4/]	7.6	92[4/]

1/ Data for District of Columbia 100,000 gpd physical-chemical pilot plant. Table from D. F. Bishop, T. P. O'Farrell, and J. B. Stamberg, "Physical-Chemical Treatment of Municipal Wastewater." Robert A. Taft Water Research Center, October 1970 (7).
2/ Intermittent Operation, percent removal based on intermittent influent concentration.
3/ Accumulated percent removal.
4/ Ion exchange placed after adsorption.

TABLE 5
BOD REMOVAL[1/]

Month (1970)	Influent (mg/l)	Clarification Residual (mg/l)	Clarification Percent Removal[3/]	Filtration Residual (mg/l)	Filtration Percent Removal[3/]	Ion Exchange[2/] Residual (mg/l)	Ion Exchange[2/] Percent Removal[3/]	Adsorption Residual (mg/l)	Adsorption Percent Removal[3/]
March	142	31.4	78	23.7	83	16.7	88	3.7	98
April	126	28.3	78	24.3	81	18.6	85	6.4	95
May	158	26.1	83	19.4	88	12.6	90	6.5	96
June	111	18.1	84	15.1	86	9.6	90	7.5	93
July	99	13.0	86	11.8	88	7.8	92	3.0	97
August	98	16.2	83	13.9	86	4.3	93[4/]	4.7	95[4/]

1/ Data for District of Columbia 100,000 gpd physical-chemical pilot plant. Table from D. F. Bishop, T. P. O'Farrell, and J. B. Stamberg, "Physical-Chemical Treatment of Municipal Wastewater." Robert A. Taft Water Research Center, October 1970 (7).
2/ Intermittent Operation, percent removal based on intermittent influent concentration.
3/ Accumulated percent removal.
4/ Ion exchange placed after adsorption.

TABLE 6

TREATMENT OF SECONDARY EFFLUENTS BY FILTRATION, CHEMICAL CLARIFICATION AND/OR CARBON ADSORPTION 7/

			Turbidity 3/ (JTU)					TOC 3/ (mg/l)					Phosphates 3/ (mg/l)	
Plant 1/	Chem. 4/	Dose (mg/l)	In	Filt.	Filt.-Carbon	Clar.	Clar.-Carbon	In	Filt.	Filt.-Carbon	Clar.	Clar.-Carbon	In	Clar.
A-1 5/	Al	260	---	-----	------	19	11	---	-----	------	33	4	---	-----
A-2 6/	Al	400	120	-----	------	1.1	0.6	71	-----	------	30	1	---	-----
A-3 4/	Al	450	31	-----	------	0.3	------	72	-----	------	17	------	58	0.0
A-3 4/	Ca	450	31	-----	------	0.7	------	72	-----	------	19	------	58	0.0
A-4	Al	300	21	10	6.7	0.2	0.1	18	17	4	9	0	19	0.8
A-5	Ca	303	35	15	10	0.5	0.3	24	19	5	11	0	23	1.0
B-1 4/	Ca	133	9.5	-----	------	0.6	------	15	-----	------	12	------	35	1.0
B-2 4/	Ca	151	18	-----	------	0.6	------	20	-----	------	10	------	33	0.4
B-3	Al	350	90	7.1	5.5	0.2	0.2	19	14	4	8	0	21	0.0
B-4	Ca	227	200	15	8.7	1.6	1.3	40	18	5	13	0	29	0.5
C-1 4/	Al	300	13	-----	------	0.3	------	15	-----	------	11	------	24	0.8
C-1 4/	Ca	300	13	-----	------	-----	------	15	-----	------	13	------	24	2.0
C-2	Ca	151	14	8.8	6.5	0.9	0.7	12	12	2	9	0	20	2.8
D-1 4/	Al	150	130	-----	------	0.8	------	37	-----	------	16	------	11	0.0
D-1 4/	Ca	150	130	-----	------	7.0	------	37	-----	------	18	------	11	0.4
E-1	Ca	378	120	39	28	0.9	3.3	189	157	22	116	14	---	0.2

1/

Symbol	Source	Type of Treatment	Type of Waste
A	Batavia	Trickling Filter	Domestic
B	Lebanon	Activated Sludge	Domestic
C	Hamilton	Activated Sludge	Mixed
D	Remington	Trickling Filter	Domestic
E	"Primary"	Overloaded Trickling Filter	Domestic

2/ Ca = lime as CaO; Al = alum as $Al_2(SO_4)_3 \cdot 14H_2O$.

3/ In = input value; Filt. = after filtration only; Clar. = after chemical clarification and filtration; Filt.-Carbon = after filtration and carbon adsorption; Clar.-Carbon = after chemical clarification, filtration and carbon adsorption.

4/ Indicates jar tests; not filtered.

5/ Partially clarified with alum.

6/ 38-minute empty-bed contact time; all others 20-minute bed contact time.

7/ Data from D. F. Bish, L. S. Marshall, T. P. O'Farrell, R. B. Dean, B. O'Connor, R. A. Dobbs, S. H. Griggs, and R. V. Villiers, "Studies on Activated Carbon Treatment." Journal Water Pollution Control Federation, February 1967 (2).

shows the removal of turbidity, TOC and phosphate by either filtration; filtration and carbon adsorption; filtration and chemical clarification; or filtration, chemical clarification and carbon adsorption. As can be seen in this table, chemical clarification and filtration alone removes TOC from an influent range of 12-72 mg/l to an effluent range of 8-33 mg/l. When the effluent from this clarification step is passed through the carbon adsorption columns, the TOC is further reduced with the final effluent having 1 mg/l or less of TOC. This suggests that the extent of residual TOC in the original secondary effluent was an unadsorbable fraction on the order of 1 mg/l (2).

A 0.3 MGD granular activated carbon pilot plant has continuously treated unfiltered activated sludge effluent from the Pomona water reclamation plant from June 1965 through July 1969 (11) (12). Successful backwashing of the first stage activated carbon column, which served as a filter and adsorber, made pretreatment of the secondary effluent unnecessary. The average TOC concentrations in the influent and effluent from this pilot plant study were 12 and 3 mg/l respectively (75 percent TOC removal). Table 7 summarizes the average water quality characteristics of this study.

Other municipalities which utilize carbon adsorption include Cincinnati, Ohio; Wayne County, Michigan; Cortland, New York; Leetsdale, Pennsylvania; South Tahoe Public Utility District, California; and Nitro, West Virginia (3) (6). Except for Cincinnati, TOC data were not available. Cincinnati removes 86 percent of the TOC in its physical-chemical wastewater facility (6).

TABLE 7

CARBON ADSORPTION PILOT PLANT
AVERAGE WATER QUALITY CHARACTERISTICS[1/],[2/]
JUNE 1965 to JULY 1969

PARAMETER		INFLUENT	EFFLUENT
SUSPENDED SOLIDS	mg/l	9	0.6
COD	mg/l	43	10
DISSOLVED COD	mg/l	30	8
TOC	mg/l	12	3
NITRATE as N	mg/l	8.1	6.6
TURBIDITY (Jtu)		8.2	1.2
COLOR (Platinum-Cobalt)		28	3
ODOR (Ton)		12	1
CCE	mg/l	-	0.026
BOD	mg/l	3	1

1/ Data for Pomona, California, Water Reclamation Plant.
2/ Table from J. N. English, A. N. Masse, C. W. Carry, J. B. Pitkin, and J. E. Haskins, "Removal of Organics from Wastewater by Activated Carbon." Advanced Waste Treatment Seminar, San Francisco, California, October 28-29, 1970 (12).

Industrial wastewater treatment facilities experience wide fluctuations in raw wastewater characteristics. Biological systems operate least effectively under fluctuating temperature and pH conditions, and in addition, dyes, detergents and other refractory contaminants can pass through these systems without receiving any degree of treatment. Toxic wastes upset biological waste treatment facilities. Due to these and other factors, carbon adsorption systems are being utilized by industry (6). Table 8 lists a variety of industries which presently treat their wastewaters by carbon adsorption techniques.

An investigation of the removal of color and organic carbon from a paper mill bleaching effluent was conducted at Continental Can Co., Augusta, Georgia (13). This investigation utilized only the chemical clarification step in the physical-chemical process. Aluminum chloride was found to be the most economical coagulant, removing 80 percent of the color and 30 percent of the total carbon.

Costs

The major portion of the operating costs for treatment of wastes by activated carbon relates to the amount of carbon exhausted per unit of wastes treated. Based on the pilot plant study, Rocky River, Ohio, will construct a 10 MGD treatment facility at a cost of $1.6 million. This is $200,000 less than the cost of the conventional activated sludge plant designed to treat this same wastewater. The annual operating cost for the adsorption portion of the process is estimated at $0.03/1000 gal. (8).

The Pomona Pilot Plant Study results indicate that the cost of a 10 MGD waste treatment facility utilizing carbon adsorption with no pretreatment of the secondary effluent would be $0.08/1,000 gal. of treated wastewater (11).

TABLE 8

INDUSTRIAL WASTE ADSORPTION TREATMENT PLANTS1/

	LOCATION	IMPURITY	AVERAGE FLOW RATE	REACTIVATION OR REGENERATION METHOD
1.	Washington, New Jersey	Polyols	100 gpm	Furnace
2.	E. St. Louis, Illinois	Nitrophenol	50 gpm	Caustic
3.	Burlington, Iowa	TNT	100 gpm	None
4.	Southampton, Pa.	Dye	350 gpm	Furnace
5.	Portland, Oregon	Insecticides	100 gpm	Furnace
6.	Conway, North Carolina	Phenol	25 gpm	Caustic
7.	Wilmington, California	Refinery Wastes	2,900 gpm	Furnace
8.	Latrobe, Pa.	Cyanide	20 gpm	-------

1/ Table from D. G. Hager and P. B. Reilly, "Clarification-adsorption in the Treatment of Municipal and Industrial Wastewater." Presented at the 42nd Annual Conference of the Water Pollution Control Federation meeting in Dallas, Texas, October 5-10, 1969 (6).

Table 9 summarizes capital and operating costs for four plants, three for secondary effluent treatment and one (Rocky River) for primary effluent treatment. These cost estimates were made by different groups and therefore differ in procedure for calculating such items as overhead, maintenance and amortization. Each plant also differs in process configuration and objective; therefore, care should be taken not to directly compare one with another (3).

The economics of a clarification-adsorption process compared to an activated sludge facility for a 10 MGD wastewater flow are given in Tables 10, 11 and 12 (6). The primary treatment portion for both the activated sludge facility and the clarification process is identical. The capital cost for a clarification-adsorption process is less than for an activated sludge facility (Table 10). The annual operating costs, on the other hand, are higher for carbon adsorption (Table 11). Combining the operating costs with amortization of capital shows that the costs of the two systems are essentially the same for the 90 percent BOD removal level (Table 12). Should a higher degree of treatment be required in the future, the clarification-adsorption system could deliver up to 95 percent BOD removal for an increase of 0.7 cent per 1,000 gal. annual operating cost. The activated sludge facility would require the addition of a "tertiary" system to achieve the 95 percent BOD removal level, thus resulting in additional capital costs. This would result in a cost much greater than the 0.7¢/1,000 gal. required for the carbon adsorption process.

ADSORBENT RESINS

Adsorbent synthetic resins are being investigated as alternatives

TABLE 9
CAPITAL AND OPERATING COSTS[1/]
GRANULAR CARBON ADSORPTION

	Pittsburgh Activated Carbon Co.	Lake Tahoe	Pomona	Rocky River
Capacity, MGD	10	7.5	10	10
Investment ($1,000)	1,489	1,306	1,670	1,600
Operating Cost (¢/1000 gal.)				
Carbon	1.20	1.18	1.10	0.69
Fuel	0.11	----	0.25	0.12
Chemicals	----	0.99	----	3.80
Power	0.85	0.75	0.85	0.55
Labor	0.74	0.40	1.50	1.10
Overhead	0.27	----	----	----
Amortization	3.07 (20 Years)	3.53 (20 Years)	4.10 (15 Years)	3.23 (20 Years)
Maintenance	0.63	0.33	0.50	0.55
Total Operating Cost	6.87	7.18	8.30	10.04

1/ Table from Arthur N. Masse, "Removal of Organics by Activated Carbon." Robert A. Taft Water Research Laboratory, August 1968 (mimeo) (3).

TABLE 10

CAPITAL COST COMPARISON[1/]
10 MGD Plant

	In Thousands of Dollars		
	Primary	Activated Sludge	Clarification Adsorption
Preliminary	75	75	75
Preaeration	98	98	98
Primary Settling	275	275	275
Activated Sludge System	--	730	--
Secondary Settling	--	200	--
Adsorption	--	--	950
Sludge Thickening	42	72	48
Sludge Dewatering	140	600	240
Disinfection	32	32	32
Buildings	200	200	200
Sludge Incineration	400	450	450
Sub Total	$1,262	$2,732	$2,368
Contingencies (20%)	250	550	470
Contractors Profit (10%)	126	273	236
Engineering, Legal, Financial (12%)	150	328	285
Total Cost	$1,788	$3,883	$3,359
Design Basis:			
BOD Removal		90%	95%
Suspended Solids		90%	95%

1/ Table from D. G. Hager and P. B. Reilly, "Clarification-Adsorption in the Treatment of Municipal and Industrial Wastewaters." Presented at the 42nd Annual Conference of the Water Pollution Control Federation Meeting in Dallas, Texas, October 5-10, 1969 (6).

TABLE 11
OPERATING AND MAINTENANCE COST COMPARISON[1/]
10 MGD Plant

	Primary	Activated Sludge	Clarification Adsorption	
BOD Removal	35%	90%	90%	95%
	Cents Per 1,000 Gallons			
Primary Treatment	3.3	3.3	3.3	3.3
Activated Sludge	---	2.2	---	---
Clarification				
Chemicals	---	---	0.3	0.3
Extra Sludge	---	---	0.1	0.1
Adsorption System	---	---	3.2	3.9
Sub Total	3.3	5.5	6.9	7.6
Incineration	2.6	3.6	3.8	3.8
Total ¢/1,000 gallons	5.9	9.1	10.7	11.4

1/ Table from D. G. Hager and P. B. Reilly, "Clarification-Adsorption in the Treatment of Municipal and Industrial Wastewaters." Presented at the 42nd Annual Conference of the Water Pollution Control Federation Meeting in Dallas, Texas, October 5-10, 1969 (6).

TABLE 12

TOTAL COST COMPARISON[1/]
10 MGD Plant

	Primary	Activated Sludge	Clarification Adsorption	
BOD Removal	35%	90%	90%	95%
	Cents per 1,000 Gallons			
Operating and Maintenance	5.9	9.1	10.7	11.4
Amortization of Capital (5%--20 years)	4.0	8.7	7.2	7.2
Total ¢/1,000 gallons	9.9	17.8	17.9	18.6

1/ Table from D. G. Hager, and P. B. Reilly, "Clarification-Adsorption in the Treatment of Municipal and Industrial Wastewaters." Presented at the 42nd Annual Conference of the Water Pollution Control Federation Meeting in Dallas, Texas, October 5-10, 1969 (6).

to carbon or for specialized application. At the present stage of development, adsorbent resins are not likely to replace carbon (7).

Vanderbilt University is studying the properties of chemcoke, an apparently competitive material for activated carbon. The study will determine the ability of chemcoke to adsorb refractory materials (14).

OXIDATION PROCESSES

The Pacific Northwest Water Laboratory has investigated the efficiency of oxidation ponds for removal of carbon from pulp and paper mill wastewaters (15). They found that for an unbleached Kraft pulp mill, the oxidation ponds removed approximately 60 percent of the TOC and COD and 90 percent of the BOD. For a sulfite pulp mill, the removals were 20 percent for COD, 32 percent for TOC and 73 percent for BOD.

A variety of chemical oxidation processes have been investigated, such as chlorine catalyzed by ultraviolet light, metal catalyzed photo-oxidation, and ozone. Of these, only ozone appears to be technically feasible. Airco, Inc., is currently constructing a 50,000 gpd plant to determine its feasibility(4).

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GPO 835-291