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Meeting Minutes Transmittal

200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Managers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

The undersigned indicate by their signatures that these meeting minutes reflect the actual occurrences of the above dated Unit Managers Meeting.

_____ Date: 9-26-93
Clifford E. Clark, Unit Manager, RL

_____ Date: 10-7-93
Daniel L. Duncan, RCRA Program Manager, EPA Region 10

_____ Date: _____
Robert King, Unit Manager, Washington State Department of Ecology

---

200 Area Effluent Treatment Facility (ETF) WHC Concurrence

_____ Date: 11-16-93
Don Flyckt, Contractor Representative, WHC

Purpose: Discuss Permitting Process

Meeting Minutes are attached. The minutes are comprised of the following:
Attachment 1 - Agenda
Attachment 2 - Summary of Discussion and Commitments/Agreements
Attachment 3 - Attendance List
Attachment 4 - Action Items
Attachment 5 - C-018H, 242-A Evaporator/PUREX Condensate Treatment Facility Design and Construction Activities
Attachment 6 - UVOX -vs- GAC

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Attachment 1

200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Managers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

Agenda

1. PREVIOUS MEETING MINUTES

2. PROGRAM STATUS

   - Design and Construction

3. C-018H RCRA TOPICS

   - UVOX -vs- GAC Presentation by Peroxidation Systems Inc. (PSI)
   - Status of "240" Engineering Report Approval

4. GENERAL TOPICS

   - Action Items
     - Past Action Items
     - New Action Items
   - Schedule of Next Meeting
     - Tentative Dates
     - Proposed Topics

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200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Mangers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

Action Item Status List

Action Item	Description
09-17-92:1	Status of Ecology's written verification that Project C-018H has interim status. ACTION: C. Clark (RL) OPEN
09-17-92:2	Status of letter to RL from Ecology requesting specific information regarding efficacy of UV oxidation in treating organic compounds. ACTION: B. King (Ecology) CLOSED. RL did not receive letter from Mr. B. King, but RL sent information to Ecology in November 1992.
12-22-92:1	Deliver information regarding efficacy of granulated activated carbon treatment to Mr. B. King in Richland on 12-23-92. ACTION: A. Vogt (WHC) CLOSED
12-22-92:2	Deliver "240" Engineering Report to Mr. B. King in Richland on 12-23-92. ACTION: A. VOGT (WHC) CLOSED
12-22-92:3	Organize tour of pilot plant for Ecology. ACTION: D. Bryson (RL) OPEN

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Attachment 2

200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Managers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

Summary of Discussion and Commitments/Agreements

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1. PREVIOUS MEETING MINUTES

- There was no Unit Managers Meeting was held in January.

2. PROGRAM STATUS

- Mr. J. Noble (WHC) presented the status of the site preparation for construction (Attachment 5). He stated that some of the regulatory approvals which are necessary for construction were still outstanding, specifically the air permits and BAT/AKART approval.

  Mr. D. Duncan (EPA), who participated via telephone, asked if construction of C-018H was dependent on the RCRA permit for the RD&D facility. Mr. C. Clark (RL) and Mr. D. Flyckt (WHC) responded that the two are not tied together.

  Mr. Duncan also inquired about the status of the delisting petition for C-018H, and requested that a copy of the letter and information that was sent to EPA Headquarters be sent to him. He also suggested that RL get confirmation in writing from EPA that approval of the delisting petition data does not require actual feed from the 242-A Evaporator.

  Mr. Flyckt confirmed that actual feed will be available and used in the RD&D by August 1993.

3. C-018H RCRA TOPICS

- Mr. E. Froelich of Peroxidation Systems Inc. (PSI), the subcontractor providing the ultraviolet oxidation (UVOX) system for the ETF, presented technical and financial information comparing the efficacy of UVOX and granulated activated carbon (Attachment 6). The presentation was made to supplement data submitted to Ecology in the "240" Engineering Report.

  Mr. M. Jaraysi (Ecology) asked Mr. B. King (Ecology) if he was satisfied that UVOX was an acceptable means of treating organics, assuming the information presented was recalculated and verified. Mr. King said that he would not be satisified until he checked with other experts to confirm Mr. Froelich's presentation. Mr.

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King expressed disappointment that the information hadn't been provided sooner.

- Mr. King requested that the "240" Engineering Report be officially revised to incorporate the information presented at the unit mangers meeting, including the new tables.

  Mr. King said that he would attempt to review and, if possible, approve the additional information for the "240" Engineering Report to support start of construction by March 15, 1993.

4. GENERAL TOPICS

- Regarding the status of action item 9-17-91:1, Mr. Clark stated that he had discussed with Mr. T. Michelena (Ecology) RL's request for a letter explicitly granting interim status to the ETF, and that Mr. Michelena committed to sending the letter to Mr. Clark. No date for transmittal of the letter was specified. This closed the action item and generated a new action item for Mr. Michelena. Action items 9-17-92:2, 12-22-92:1 and 12-22-92:2 were closed. Action item 12-22-92:3 was left open for Mr. D. Bryson (WHC) to arrange a tour of the pilot plant.

- There were four new action items generated (Attachment 4).

- The next Unit Managers Meeting was scheduled for March 2, 1993.

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Attachment 3

200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Managers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

Attendance List

Name	Organization	Phone #
Dana Bryson	RL	509-372-0738
Clifford E. Clark	RL	509-376-9333
Emery M. Froelich	PSI	602-790-8383
Bob King	Ecology	206-459-6859
Paul Kufrin	PSI	602-790-8383
Jim Gleason	PSI	602-790-8383
Don Flyckt	WHC	509-372-3142
A. K. Vogt	WHC	509-376-2352
Earle Marvin	KEH	509-372-2607
Jim Kelly	WHC	509-376-4896
Ken Sauda	JGC	703-713-9000
Gary Mezger	RL	509-376-5039
Paula Davis	RL	509-372-3084
Lou Reynolds	JGC	703-713-9000
John Cook	MACTEC/GSSC	509-946-0176
Randall N. Krekel	RL	509-376-4264
Dan Duncan	EPA (via telecon)	206-553-6693
Melodie Selby	Ecology	509-736-3021
Moses Jaraysi	Ecology	509-736-3016
Jan Fields	WHC	509-376-8556

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Attachment 4
200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Mangers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

New Action Items

Action Item	Description
02-11-93:1	Send to Dan Duncan, EPA Region 10, a copy of the letter and delisting petition information sent to EPA Headquarters. ACTION: D. Bryson (RL)
02-11-93:2	Send to Bob King (Ecology) a letter, revised cost table(s) and other information to supplement "240" Engineering Report justifying UVOX rather than GAC for organic destruction. ACTION: D. Bryson (RL)
02-11-93:3	Send video copy of PSI's UVOX presentation to Dan Duncan (EPA) and provide 2 copies to Bob King (Ecology). ACTION: A. Vogt (WHC)
02-11-93:4	Ecology to send a letter to Cliff Clark (RL) stating that C-018H has interim status. No commitment date. ACTION: T. Michelena (Ecology)

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Attachment 5

200 AREA EFFLUENT TREATMENT FACILITY (ETF)
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

Design and Construction Activities

Handout by Jack Noble, WHC

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DESIGN ACTIVITIES

- WATER, ELECTRICAL AND COMMUNICATION SYSTEM DESIGN PACKAGES ARE COMPLETE
- COLLECTION SYSTEM - 30% DESIGN REVIEW
- DISPOSAL SYSTEM - 30% DESIGN REVIEW

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CONSTRUCTION ACTIVITIES

- WATERLINE SYSTEM CONSTRUCTION
- ELECTRICAL SYSTEM CONSTRUCTION
- COMMUNICATION SYSTEM CONSTRUCTION
- DESIGN/CONSTRUCT CONTRACT (JGC CORP.)

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START OF CONSTRUCTION

- DESIGN MEDIA
- PRELIMINARY SAFETY ANALYSIS REPORT
- PERMIT APPROVALS

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Attachment 6

200 AREA EFFLUENT TREATMENT FACILITY (ETF)
Unit Managers Meeting
7601 Clearwater, Suite 102
Kennewick, Washington

February 11, 1993
1:00 to 2:30 p.m.

Packet of information describing ultraviolet oxidation and comparisons of ultraviolet oxidation versus granulated activated carbon.

Handout by JGC, presentation by PSI

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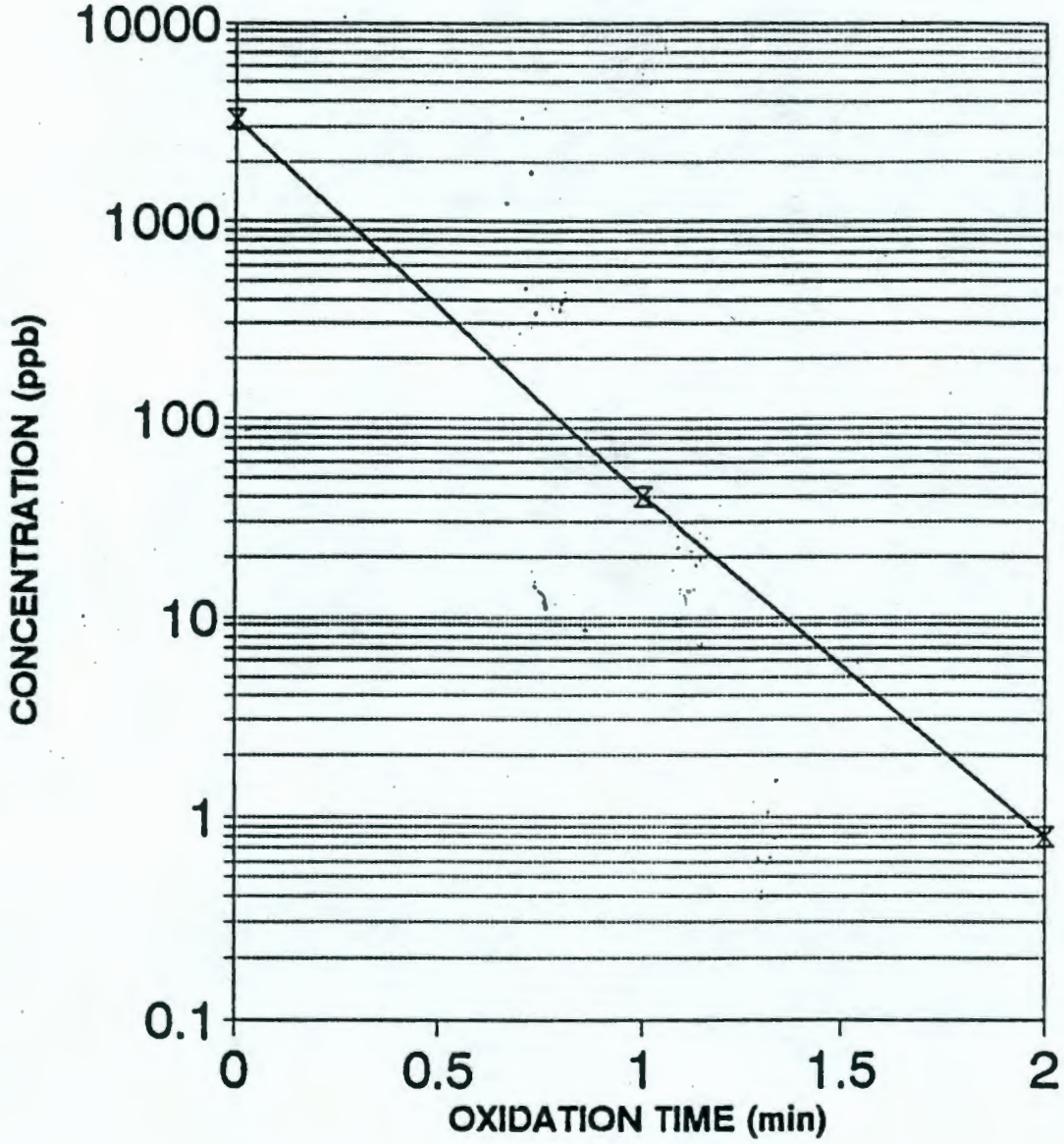
$$H_2O_2 \xrightarrow[<400\ nm]{UV} 2\ OH\bullet$$

UV/OXIDATION PROCESS

- FORMATION OF OH•
- UV PHOTO ACTIVATION
  - DIRECT OXIDATION
  - OTHER RADICALS
  - INCREASE REACTIVITY

UV/OXIDATION
KINETICS



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PROCESS CONSIDERATIONS

- ORGANIC CONCENTRATION
- TYPE OF ORGANIC
- INORGANIC MATRIX
- SUSPENDED SOLIDS

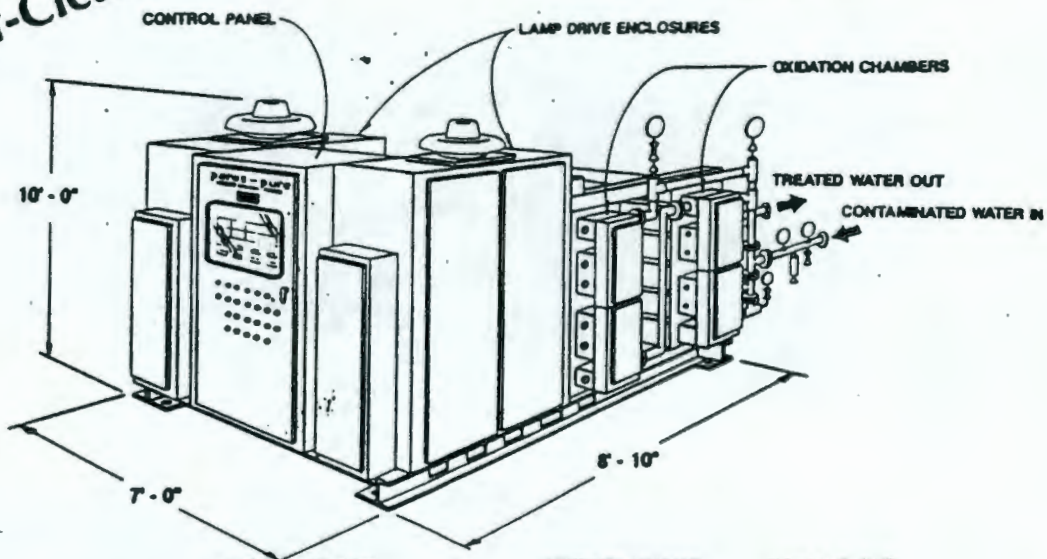
perox-pure™

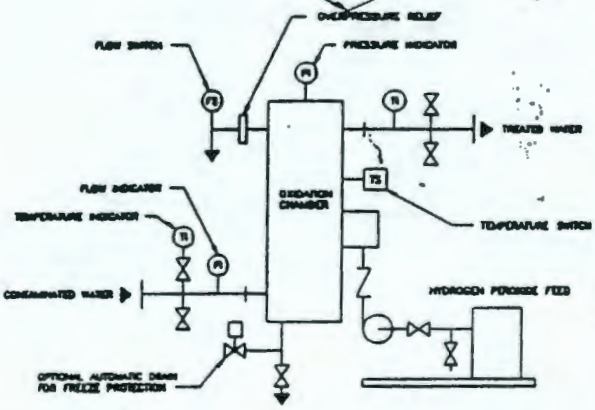
ORGANIC DESTRUCTION PROCESS

MODULAR TREATMENT SYSTEM

MODEL E-360

Now Self-Cleaning





SPECIFICATIONS	Model E-360	
Flow Rate: Maximum	200 gpm	800 gpm
Connections:	150# Flange	150# Flange
Inlet:	3"	6"
Outlet:	3"	6"
Power Supply:	3 pH/60Hz/480V, 360KW (2 @ 180 KW)	
Electrical Encl.:	NEMA 3R	
Material - Wetted Parts:	Quartz, Fluoropolymers	
External Parts:	Enameled Steel	
Weight - Shipping:	12500 lbs.	
Operating:	13800 lbs.	

The perox-pure™ chemical oxidation system consists of modular, skid-mounted equipment designed to treat water contaminated by dissolved organic compounds. Bench-scale process evaluations will determine pretreatment requirements (if any) and the oxidation time necessary for the desired treatment level. Full-scale oxidation chamber volume, UV requirements and oxidant dosage are then selected.

The perox-pure™ system incorporates corrosion resistant fluorocarbon-lined oxidation chambers and horizontally mounted medium pressure UV lamps. Indicators are provided to monitor performance of each lamp. A sequential hydrogen peroxide addition feature provides easy process optimization for maximum economy. In addition, a patented tube cleaning device maximizes performance and minimizes maintenance time. The cleaning device is automatic and self propelled, requiring no external actuating mechanism or sliding shaft seals. Other design features include shop-wired and tested control panels interlocked with personnel and process safety features to shut-off power and display the cause at preset conditions. Installation is quick and easy.

The perox-pure™ system and its components are covered by numerous issued and pending patents.

Peroxidation Systems Inc.

5151 E. Broadway, Suite 600 Tucson, Arizona 85711 602-790-8383 FAX 602-790-8008

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perox-pure™ EQUIPMENT

- HIGH INTENSITY LAMPS
- PATENTED REACTOR DESIGN
- H_2O_2 DOSING FLEXIBILITY
- AUTOMATIC TUBE CLEANER
- SAFETY INTERLOCKS
- PROGRAMMABLE CONTROLLER

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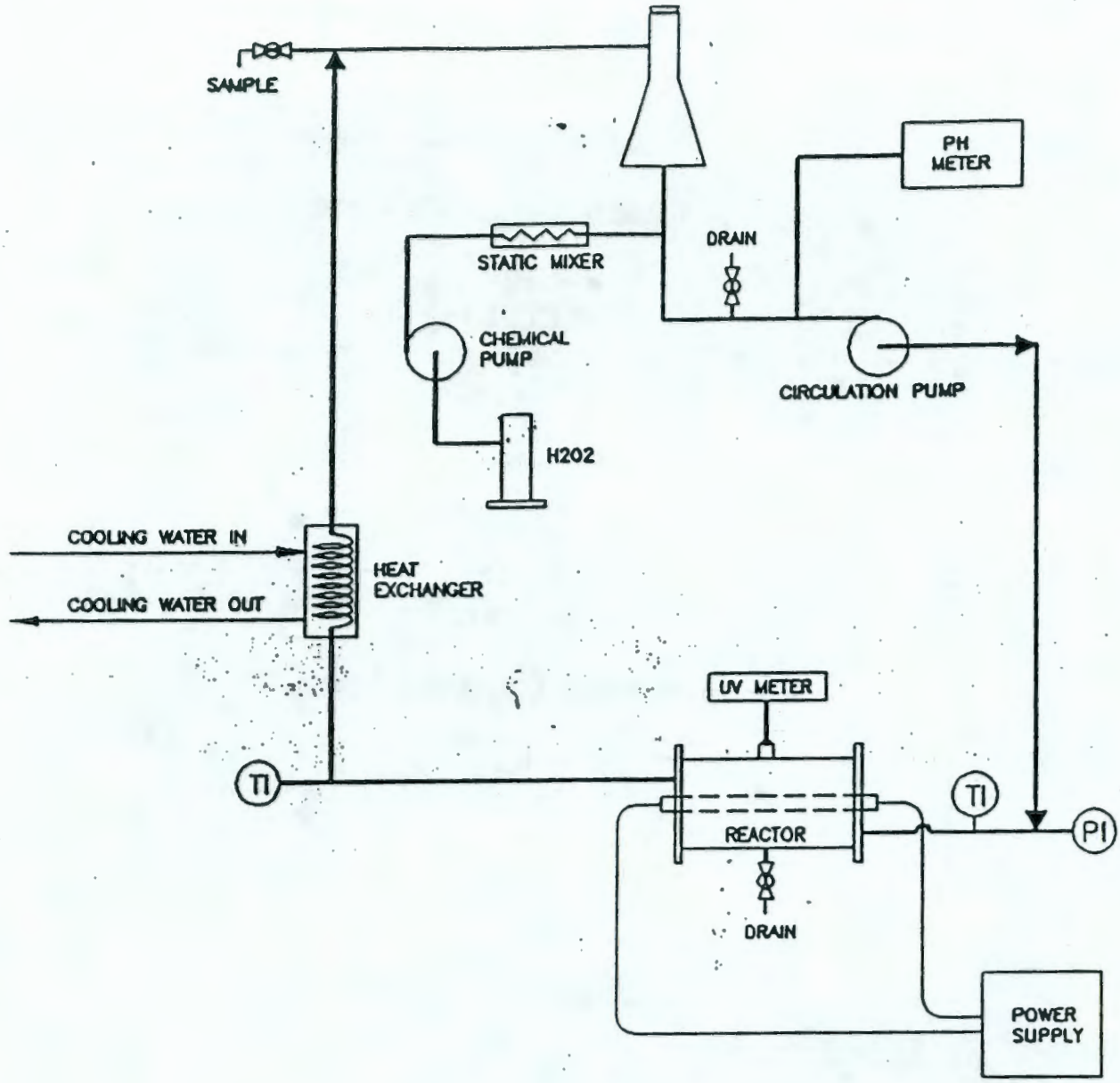
FIGURE 1



BENCH TEST UNIT DIAGRAM

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Table 2

Chemical Compounds Used in Synthetic Solution

Group	Compounds	Weight (μg)
	Inorganic Compounds	
I	NH_4	12,120,000
I	$(NH_2CO_2NH_4)$	3,180,000
I	Na_2S	3,040,000
I	Na_2SiO_3	2,000,000
II	HNO_3	820,000
II	$Ca(NO_3)_2$	217,260
II	$Al(NO_3)_3$	198,560
III	H_2SO_4	54,090
III	K_2CrO_4	4,960
	Inorganic Compounds	
IV	KF	57,000
IV	KCN	1,190
IV	NaCl	37,400
	H_2SO_4	As Required for
	NaOH	pH Adjustment
	Organic Compounds	
V	Acetone	37,400
V	1-Butanol	216,000
V	Chloroform	4,000
V	MIBK	1,670
V	Tributylphosphate	1,510,200
V	Tridecane	1,023,800

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Table 1

Test Run Initial Conditions

Run No.	Initial Temp (°F)	Initial pH	Initial H_2O_2 Dosage
*1	50	6.0	200
*2	100	6.5	200
*3	85	6.5	200
*4	85	6.5	100
*5	85	6.5	400
6	85	6.5	200
7	85	4.5	200

* Pretreated using the stoichiometric amount of H_2O_2 at the as-is pH (10.4) to oxidize H_2S to sulfate.

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TEST RESULTS

- CONSISTENT DESTRUCTION OF TOC
- OPTIMUM H_2O_2 DOSE
- NO TEMPERATURE EFFECTS

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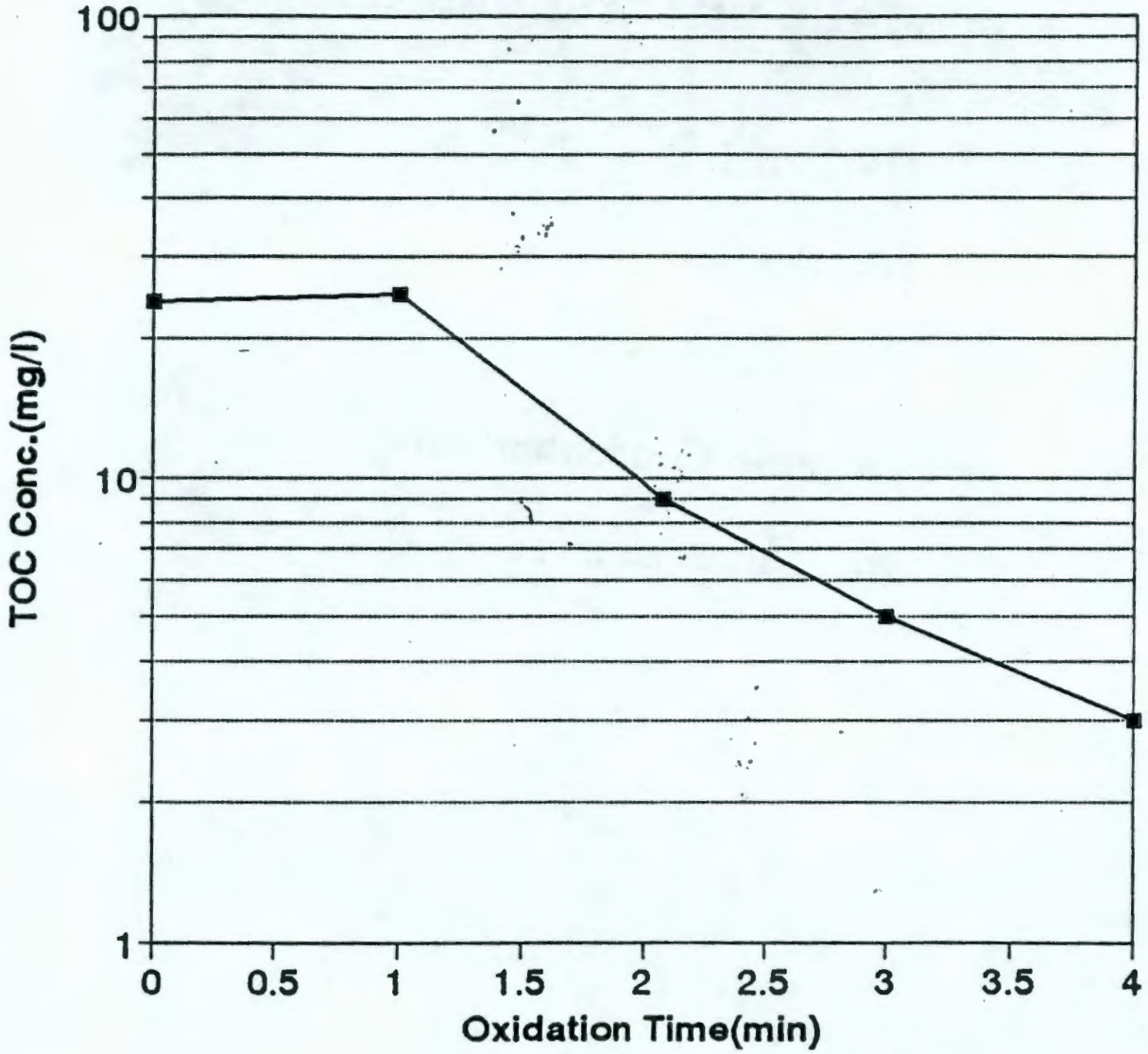
POC Synthetic Water
TOC Destruction



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SCALE-UP CONSIDERATIONS

- UV Efficiency
- UV Density
- Flow Rate
- Organic Concentration
- Inorganic Matrix

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UV DENSITY

1. Bench-Scale

   2 kW/gal

2. Full-Scale

   All "S" Reactors = 2 kW/gal

   Standard "E" Reactors = 2 kW/gal

Table 1

Hanford Surrogate Test Solution Formulation

	Concentration (ppb)			
	STS2-1	STS2-2	STS1-1	STS1-2
Organic Contaminants				
Acetone	20,000	5,000	20,000	5,000
MEK	5,000	1,000	5,000	1,000
MIBK	5,000	1,000	5,000	1,000
1,1,1-TCA	2,500	500	2,500	500
$CHCl_3$	2,500	500	2,500	500
CCl_4	2,500	500	2,500	500
Tributyl Phosphate	50,000	25,000	50,000	25,000
n-Butanol	100,000	50,000	100,000	50,000
Tridecane	5,000	1,000	5,000	1,000
Inorganic Contaminants				
Aluminum	12,500	12,500	2,500	2,500
Ammonia	500,000	500,000	25,000	25,000
Calcium	750	750	150	150
Silicon	14,500	14,500	2,900	2,900
Sodium	70,000	70,000	17,000	17,000
Copper	15,000	15,000	3,000	3,000
Silver	17,500	17,500	3,500	3,500
Mercury	500	500	100	100
Barium	5,000	5,000	1,000	1,000
Nickel	12,500	12,500	2,500	2,500
Zinc	5,000	5,000	1,000	1,000
Carbonate	100,000	100,000	10,000	10,000
Chloride	9,230	9,230	1,660	1,660
Cyanide	10,000	10,000	3,000	3,000
Fluoride	25,000	25,000	5,000	5,000
Nitrate	213,500	213,500	25,000	25,000
Sulfate	1,373,000	1,373,000	49,000	49,000

Note: Metal cyanides and carbonates precipitated from STS2-1 and STS2-2 during mixing. All precipitates were filtered before running perox-pure™ tests.

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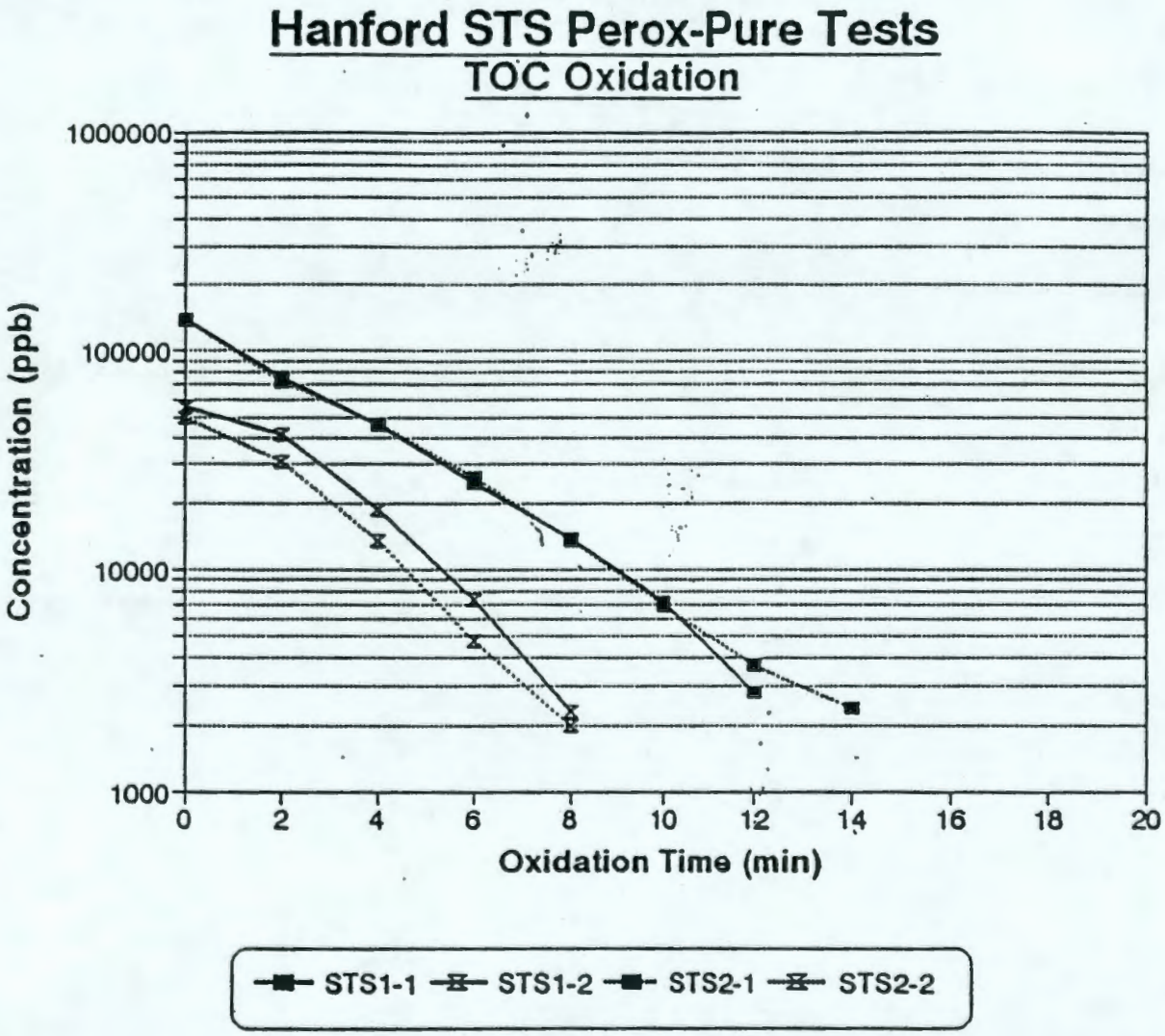
Table 4

Hanford C-018H Surrogate Test Solution
Bench-Scale Oxidation Rates

	Oxidation Rate (min^{-1})			
Contaminant	STS1-1	STS1-2	STS2-1	STS2-2
Acetone	0.53	0.69	0.34	0.49
MEK	1.58	1.32	1.15	1.72
MIBK	2.23	2.79	1.70	2.89
1,1,1-TCA	0.27	0.22	0.175	0.17
$CHCl_3$	0.23	0.22	0.14	0.165
CCl_4*	0.82 0.26	0.37 0.19	0.84 0.08	0.71 0.12
TOC	0.33	0.39	0.29	0.40

* First numbers are for first few minutes and second set are for the remainder of the oxidation.

Figure 10



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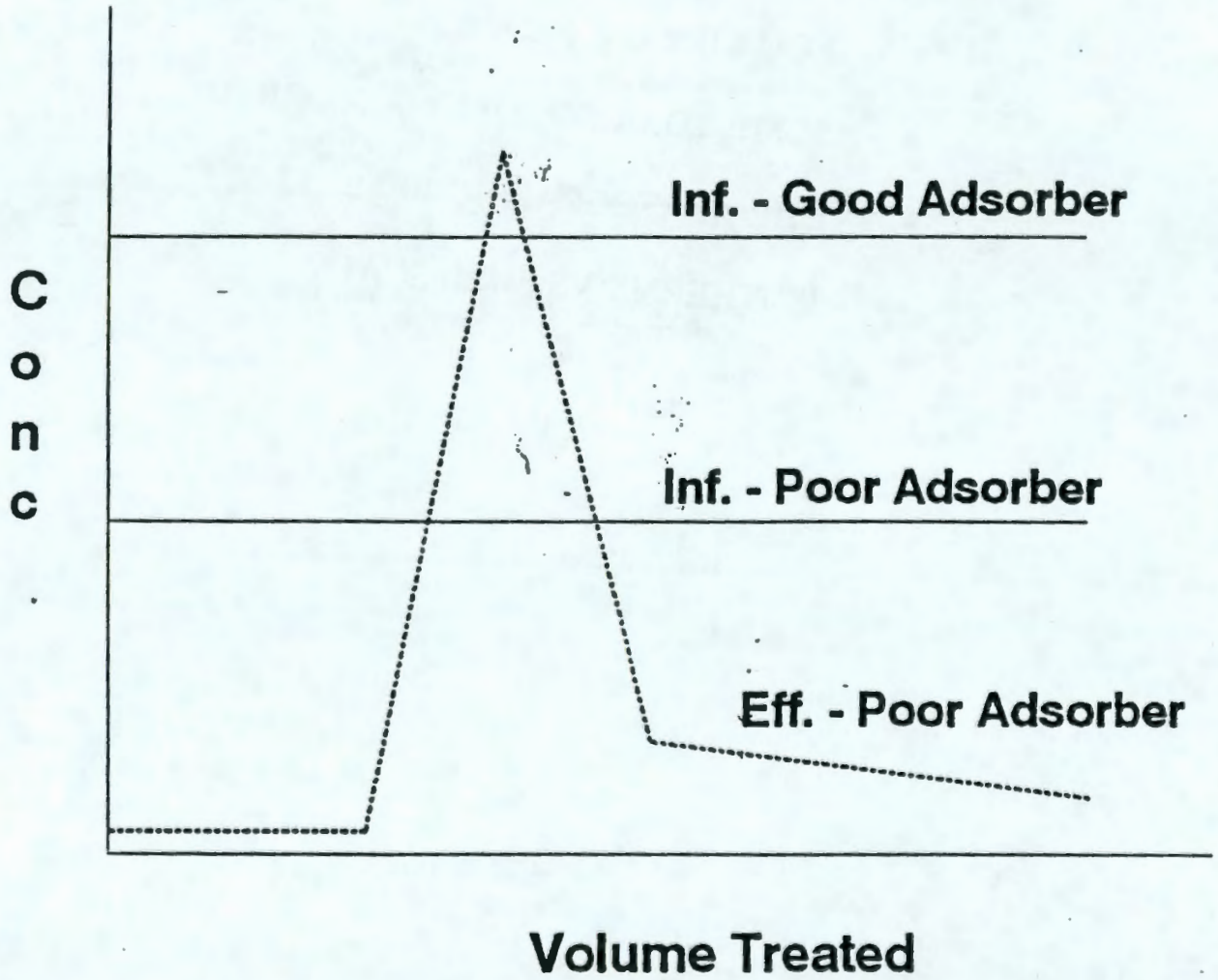
GAC AS ALTERNATIVE

- EQUILIBRIUM PROCESS
- SOME TOXICS POORLY ADSORBED
- CHROMATOGRAPHIC EFFECTS
- ISOTHERMS VS FULL-SCALE

Chromatographic Effects



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UV/OX VS GAC

	UV/OX	GAC
MIXTURES	VARIABLE COST	VARIABLE COST
EFFLUENT	PREDICTABLE	NOT PREDICTABLE (CHROMATOGRAPHIC)
DISPOSAL	NONE	DIFFICULT & COSTLY (RADIOACTIVITY)

CARBON USAGE RATE

	USAGE #/1000 GAL
PHENOL	
$10\ MG/L \frac{X}{M} = 75\ MG/G$	1.11
$0.1\ MG/L \frac{X}{M} = 6.5\ MG/G$	0.13
BIS (2-CHLOROETHYL) ETHER	
$100\ MG/L \frac{X}{M} = 400\ MG/G$	2.1
$10\ MG/L \frac{X}{M} = 6\ MG/G$	13.9
$1\ MG/L \frac{X}{M} = 0.09\ MG/G$	92.5
1,2-DCA	
$10\ MG/L \frac{X}{M} = 25\ MG/G$	3.3
$1\ MG/L \frac{X}{M} = 3.5\ MG/G$	2.4
$0.1\ MG/L \frac{X}{M} = 0.45\ MG/G$	1.9
METHYLENE CHLORIDE	
$10\ MG/L \frac{X}{M} = 15\ MG/G$	5.6
$0.1\ MG/L \frac{X}{M} = 0.09\ MG/G$	9.3

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CALGON CORPORATION

SUBSIDIARY OF MERCK & CO., INC.

CALGON ADSORPTION SERVICE
ISOTHERM REPORT

Lab No._____ SIS No._____ Date_____

Name of Plant_____

Location_____ Region_____

Sample Point_____

Contaminant Measured_____

Sample Volume_____ pH_____

Temperature_____ TOC_____

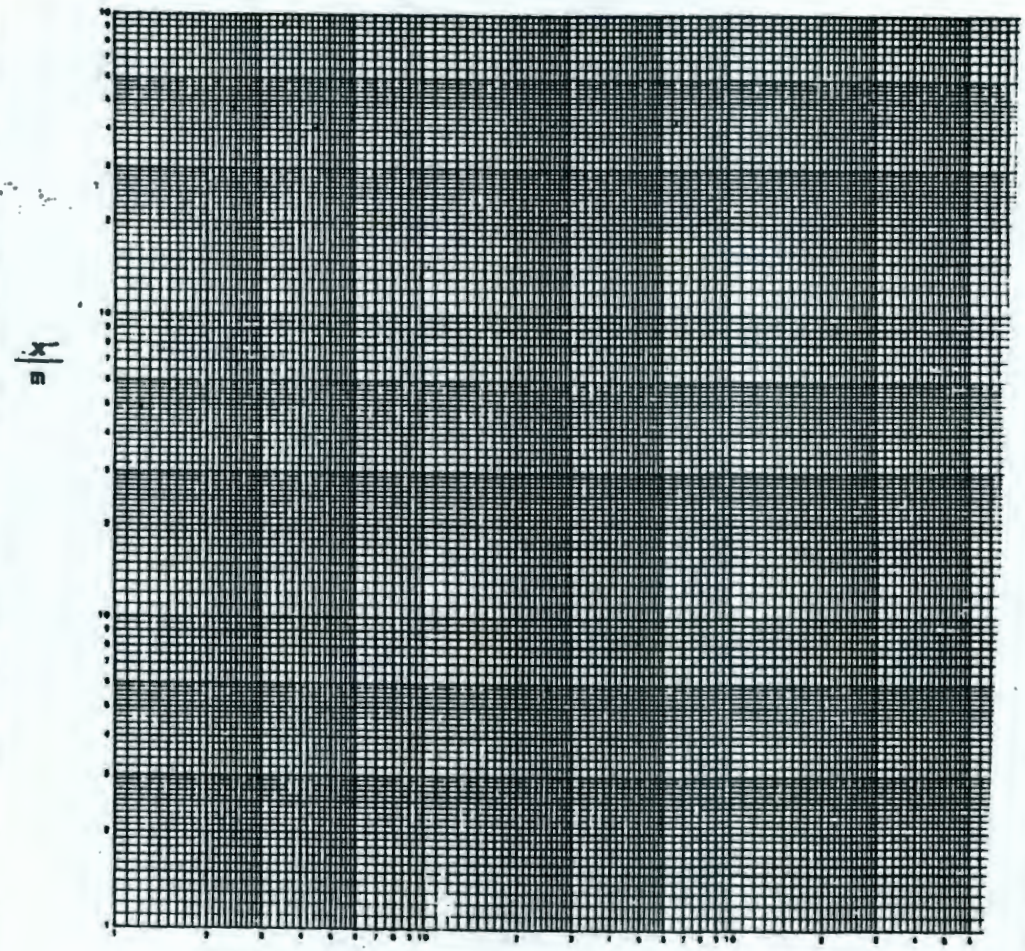
Agitation Time_____ TOC, 8μ_____

Pretreatment_____ SS_____

pH	Grams Carbon (m)	(c) Remaining mg/l	mg	Mg Adsorbed (x)	$\frac{x}{m}$

Comments:

By _____



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OPERATIONAL FLEXIBILITY

- FLOW RATE
- H_2O_2 DOSE
- PREDICTIVE TESTS
- FEED-BACK MONITORING

94130931.0199

FEB
EMF
CGL
RLP
DAC
JMF
PFK
LJJ
JDR
MD(NJ)
DB (Hilton)

DESIGN AND OPERATION OF A CARBON ADSORPTION SYSTEM TO TREAT CONTAMINATED GROUNDWATER

by

Richard T. Lynch
Calgon Carbon Corporation
San Mateo, CA

Mark H. Stenzel
Calgon Carbon Corporation
Pittsburgh, PA

John J. Aveggio
Watkins-Johnson Company
Palo Alto, CA

for presentation at:

HAZMACON '90
April 17-19, 1990
Anaheim, California

91B098.0200

The demonstrated ability of GAC to remove organic contaminants from water resulted in Congress, in passing the SDWA Amendments, establishing GAC as the "yardstick" by which other treatment technologies are to be evaluated in controlling or removing synthetic organic chemicals. In other words, when a public water supply needs to treat their water supply for organic compound removal, any other treatment technique must be at least as effective as GAC in order to be considered feasible or Best Available Technology (BAT).[2]

The first step in the design of a groundwater treatment system is to fully define the situation. The problem definition should include flow rate, influent characterization, treated water use, expected duration of treatment, possible variations in flow and contaminants, monitoring and maintenance capability, permitting issues and other site specific issues. If GAC is to be evaluated, techniques are available to accurately predict the capital and operating costs, and case studies are available either to validate the evaluation or provide guidelines for design and operation of a treatment system.

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EVALUATION TECHNIQUES — ADSORPTION ISOTHERMS

A preliminary evaluation of activated carbon performance can often be based on the liquid phase adsorption isotherm. The adsorption isotherm is a batch test designed to determine the equilibrium relationship between the organic compound(s) in the liquid, measured as concentration, and the compound(s) adsorbed on the activated carbon, stated as weight of contaminant per unit weight of activated carbon. The measure of adsorption is commonly referred to as carbon capacity.

The results of the isotherm test can often be compared to published references, and this can be useful in determining whether adsorption using activated carbon can be an effective treatment. The isotherms can also be used to provide preliminary estimates of carbon usage rates, thereby establishing preliminary economic estimates of the cost of carbon treatment. Isotherms are most useful in conjunction with dynamic testing or evaluation of actual operating results from similar situations to predict the effect of decreasing contaminant levels over time or changing contaminant mix.

When conducting VOC isotherm tests, the test conditions need to be carefully controlled to prevent volatilization of the solvents. Over the past seven years, Calgon Carbon Corporation has generated a family of single component VOC isotherms. These isotherms, and others using the same test conditions, may be used in preliminary evaluations. Figure 1 shows the results of single component isotherms for some selected chlorinated aliphatic solvents and aromatic solvents.[3,4]

ADVANCED EVALUATION -- ACCELERATED COLUMN TESTING

The effect of dynamic operating conditions, including contact time, surface loading rate and system design, has traditionally been determined using the scaled column study. The scaled column study would follow the isotherm study and would be set up based on the isotherm results. In groundwater treatment, however, the low carbon usage rates and volatility of the contaminants make the scaled column study both difficult and time consuming.

Several researchers have studied the use of small scale, rapid column tests using smaller size granules of the same activated carbon, short contact times and mathematical modeling to predict full scale system performance.[5] Calgon Carbon Corporation has developed a high pressure, mini-column technique of this type, the Accelerated Column Test (ACT), that has exhibited a high degree of correlation with full scale system operation.[6,7]

The ACT can be used to model the expected dynamic performance of an operating system to establish the contact time required and determine probable carbon usage rates. Historical or published ACT studies, and actual case studies of similar applications can be used along with isotherm data to evaluate many potential applications.[8] In these situations, this may be all that will be required to provide the basis for the sizing of the carbon treatment equipment.

Figure 2 shows the results of ACTs run on actual and prepared groundwater samples containing a single VOC contaminant. The samples used were groundwaters with little other organic contaminants present as indicated by the background TOC being less than 0.5 ppm. The operating system models had relatively short contact times (8.5 to 12 minutes) and were run until the VOC was detected in the effluent (1 ppb). The results showed that in such a system, 45-55% of the isotherm or equilibrium capacity could be realized.

Figure 3 exhibits results of other ACTS run on more complex samples. Case 1, for example, illustrates the effect of the presence of multiple components. Adding the usage rates for each single component and using 50% of the isotherm capacity would predict a usage rate of 0.25 lbs/1,000 gallons, so it can be seen that in treating a mixture, the capacity can be reduced. Cases 2 and 3 show the advantage of adding a second stage to the adsorption system resulting in a 33% reduction in carbon usage over the single stage system. Case 4 illustrates that the presence of background organic contaminants may reduce the capacity of activated carbon for the contaminants of interest. In this case, chloroform exhibits only 37% of the isotherm capacity in the presence of 6 ppm TOC, which is 20% less than the capacity for chloroform in pure water.

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In considering these ACT studies on VOC removal, it can be concluded that low level, single contaminant situations with low background organic contamination can result in 45-55% of the isotherm capacity being achieved. When the situation becomes more complex, the actual capacity can be reduced and may warrant a second stage to optimize carbon usage. Carbon use rates of 60-80% of the isotherm capacity may be obtained in many cases by operating carbon beds in series. In these systems, the carbon in the first bed is more effectively used by allowing the adsorption zone to move into the second bed. In any case, an ACT on the specific sample is useful to establish reliable performance characteristics.

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ADSORPTION SYSTEM DESIGN AND ECONOMICS

The downflow, fixed bed adsorber is generally the best design for groundwater treatment. The water enters at the top of the adsorber, is equally distributed by the flooded, packed bed design, and is collected by slotted screen collectors across the bed cross-section at the bottom of the vessel. A pressure-type adsorber is normally used as it occupies less space due to higher surface loading rates (up to 10 gpm/ft^2) compared to gravity flow units. They also can be used as an in-line treatment step so repumping is not required. A fixed bed pressure adsorber is usually an ASME coded, carbon steel pressure vessel with a corrosion resistant lining for areas where the activated carbon is in contact with the steel. A single stage adsorber can be provided with in-bed sample ports to anticipate breakthrough of the contaminants. Two pressure adsorbers will constitute the two-stage design where the second adsorber always contains the freshest carbon, and the first stage adsorber is the unit that contains the most fully utilized carbon.

Typically, 10 ft. diameter adsorbers containing 20,000 lbs. of granular activated carbon (GAC) are used in this type of adsorption process. This size unit is the optimal size for exchange and transport of the carbon charge. This quantity represents about 5,340 gallons on an empty bed basis, so a contact time of 8.5 minutes could treat a flow of 625 gpm.

A two-stage adsorption system complete with process, utility and carbon transfer piping, can be installed on an existing foundation and provided with 40,000 lbs. of GAC for approximately $200,000. An additional $50,000 may be required for site preparation, foundation and tie-ins. A single stage system usually results in a total expenditure of about $125,000 to $150,000.

The following example illustrates the methodology that can be used for a preliminary estimate. The example conditions are:

Flow:	600 gpm (0.864 mgd)
Contaminant:	Trichloroethylene (TCE)
Concentration:	180 ppb
Treatment Objective:	<5 ppb
Background TOC:	Negligible (<0.5 ppm)
Installation:	West Coast Location

Based on the evaluation procedure discussed, the following design assumptions are made:

System Design:	Two 20,000 lb. adsorbers in parallel
Contact Time:	17 minutes (300 gpm/vessel)
Isotherm Capacity:	25 mg TCE/gm GAC (Figure 1)
% Capacity Realized:	50%
Estimated Capacity:	12.5 mg TCE/gm GAC
Estimated Usage:	0.12 lbs. GAC/1,000 gallons
Estimated Annual Usage:	40,000 lbs. (GAC)

The estimated annual costs before tax considerations would be as follows:

Amortization of Capital:	$30,800 (8.75% for 10 yrs.)
Maintenance:	10,000 (5% of capital)
Energy Costs:	4,700 (8¢/KWH)
Carbon Usage:	50,000
Annual Cost:	$95,500 (29.4¢/1,000 gallons)

The carbon costs assume that the spent carbon is removed and reactivated prior to any further dispostion, and the system is resupplied with virgin (new) bituminous coal based GAC. The overall cost figure above is consistent with the EPA estimates of 34¢/1,000 gallons for systems below 1 mgd and 99% removal of TCE up to 500 ppb.

CASE STUDY - WATKINS-JOHNSON COMPANY

An example of a successful application of carbon adsorption for groundwater treatment is the experience of the Watkins-Johnson Company in Scotts Valley, California. Watkins-Johnson is one of the leading contractors for defense electronics and communications systems. The site in Scotts Valley, near Santa Cruz, has been in operation since 1959 and now employs 700 workers. In the past 30 years, the town of Scotts Valley has grown such that the plant is now in an essentially residential area.

In 1986, a spill incident led to chlorinated solvents, primarily trichloroethylene (TCE), entering the groundwater. A perched groundwater zone, and eventually the Santa Margarita aquifer, became contaminated with the solvent. The groundwater flow in the area was away from any drinking water source, but the aquifer is a source for the surface water of Bean Creek (part of the San Lorezno River Watershed). Based on the discovery of the contamination, Watkins-Johnson decided to contain the plume of contamination.

Based upon historical data from 60 monitoring wells on the plant property, a pumping system was designed to contain the plume by pumping 350 gpm from 4 extraction wells (3 that extended nearly 150 feet into the Santa Margarita aquifer and a lower flow well, approximately 100 feet deep, to collect water from the perched zone). The well system is capable of pumping up to 1,000 gpm if necessary.

The treatment system was specified to treat up to 500 gpm and reduce TCE at 60 ppb and trans 1,2 dichloroethylene (DCE) at 5 ppb to below 0.5 ppb each. The discharge was to be to surface water at Bean Creek and would have to satisfy NPDES permits.

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TREATMENT SYSTEM SELECTION

Watkins-Johnson considered both air stripping and activated carbon adsorption as viable means to achieve the treatment objectives. Activated carbon adsorption was selected as the treatment system for quantitative reasons.

As Watkins-Johnson wanted to move rapidly to effect treatment, they viewed air stripping as a potentially more lengthy process due to the uncertainty of obtaining an air discharge permit from the local air district and uncertainty about whether off-gas control might be required. The adsorption system, however, was seen to be more flexible in view of changing flow and contaminant levels, easier to operate and assured of meeting the treatment objectives.

After reviewing proposals, Watkins-Johnson selected Calgon Carbon Corporation to provide a two-stage adsorption system to treat the contaminated groundwater. The Calgon Carbon design allowed for ease of two-stage operation, convenient carbon discharge and fill, and could be readily available for installation. Starting the project on July 3, 1986, the adsorption system was on-site and installed on September 10, 1986. Calgon Carbon also assured Watkins-Johnson of the ability to remove the spent carbon and recharge the adsorbers with fresh carbon.

The complete treatment system is shown in the schematic in Figure 5. The four extraction wells pump groundwater to a 5,000 gallon surge tank. The surge tank is serviced by two feed pumps, each of which can deliver 350 gpm to the treatment system. Both pumps are necessary to provide maximum flow of 500 gpm. Discharge from the treatment system can be directed to surface water discharge at Bean Creek, aquifer recharge and/or plant use.

The cost for the entire remediation system was approximately $500,000; with about 25% of this expenditure for the extraction wells, 35% for the pumps and piping, and 40% for the adsorption system which included 40,000 lbs. of GAC.

SYSTEM OPERATION REVIEW

The treatment system has operated essentially continuously since startup on October 12, 1986. Minor shutdowns have been taken for well maintenance, one incident of iron buildup on the GAC bed from the perched zone (backwashed to maintain operation), and a 6 day shutdown due to the October 1989 earthquake. As the adsorption system was constructed to requisite seismic standards, it was unaffected by the earthquake and was able to resume normal operation.

The system pressure drop across the two beds operated in series has been 8-12 psig, except when iron buildup required backwash. In addition to chlorinated solvents being less than 0.5 ppb in the effluent, addtional water characteristics include pH of 6.8-7.8, dissolved oxygen of 5-10 ppm and generally very low turbidity.

Although originally intended for discharge, the success of the treatment system has allowed Watkins-Johnson to begin using the treated water in the plant. In February 1987, the water supply permit was amended to allow use of the carbon treated water for both potable and process use. It was expected that reuse would be in the range of 5-10%. The reuse program has been successful, with reuse averaging 25-45 gpm which has been as high as 21% of the treated water from the GAC system.

In April 1988, the plant also decided to use some of the treated water to recharge the perched zone downgradient of the extraction well. The recharge rate was, at times, as high as 50 gpm or 25% of the extraction rate, but was reduced to 15 gpm or 7% of the extraction rate to preserve slope stability in the recharge zone.

The operating results of the carbon treatment system are summarized in Figure 6. The contaminant levels of TCE and DCE started at higher levels than expected, but have steadily decreased over time. Also, upon startup of the treatment system, low levels of other VOC such as dichloroethane and methylene chloride were detected. The flexibility of the adsorption system is such that these contaminant are also reduced to below 0.5 ppb, although the usage rate is highe than would be predicted if only TCE and DCE were present.

EPA Method 601 samples are taken at the influent, midpoint and discharge of the adsorbers on a weekly basis. Carbon exchange is scheduled when a VOC is detected above 0.5 ppb in the system efflue The carbon usage rate at breakthrough of the second bed has been consistent (between 0.34 and 0.42 lbs/1,000 gallons.

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SOUTHERN PACIFIC
IONPURE
WASHOE COUNTY

LOCKHEED - KSC
LOCKHEED - AEROMOD
LAWRENCE LIVERMORE NATIONAL LABS
- SITE A
- SITE B
- SITE F
SACRAMENTO ARMY DEPOT
SCHERING-PLOUGH
SOLVENTS RECOVERY SERVICE OF NEW ENGLAND
SPACE BIOSPHERES VENTURES
SYNTEX
ELMORE TOYOTA
TERRADYNE
U.S. COAST GUARD
UNIFIRST

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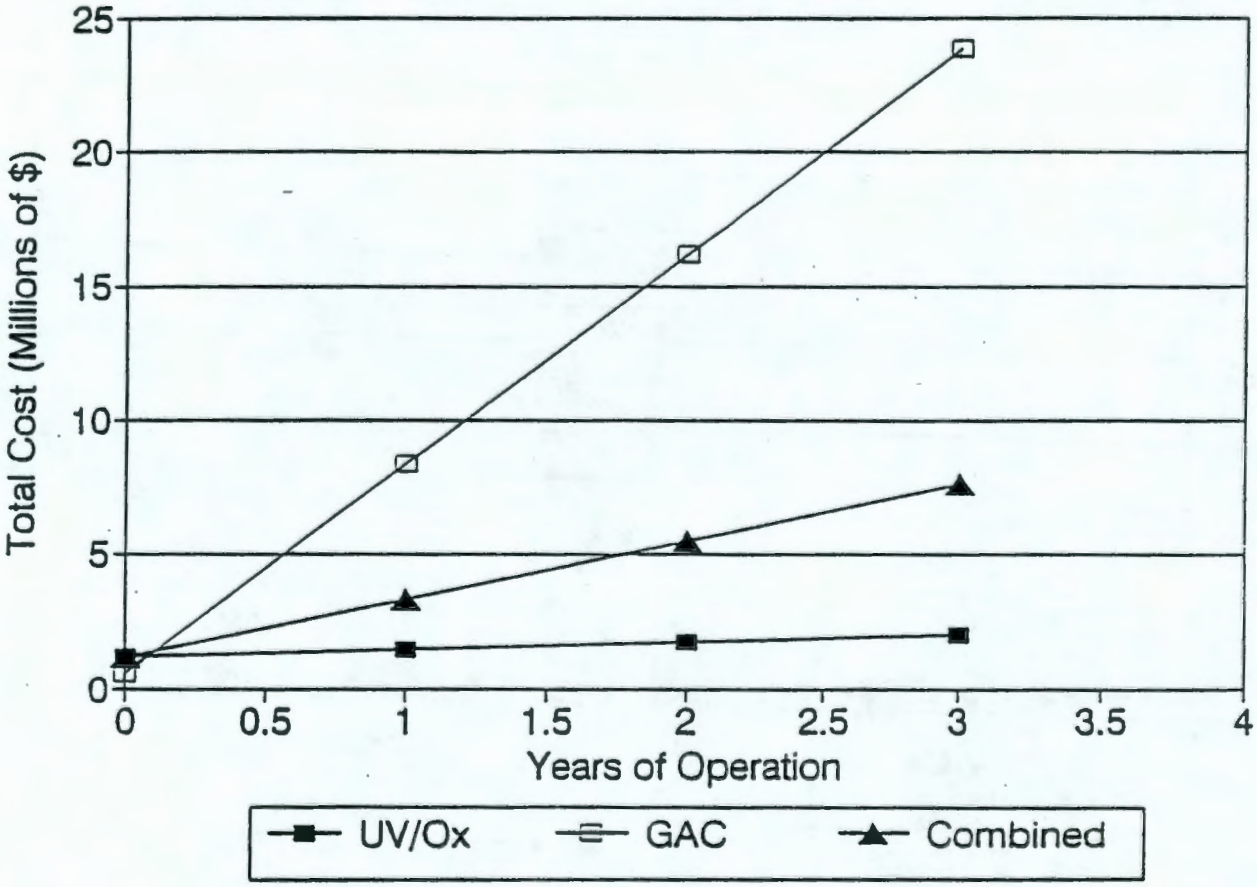
Comparison of Total Cost vs. Time



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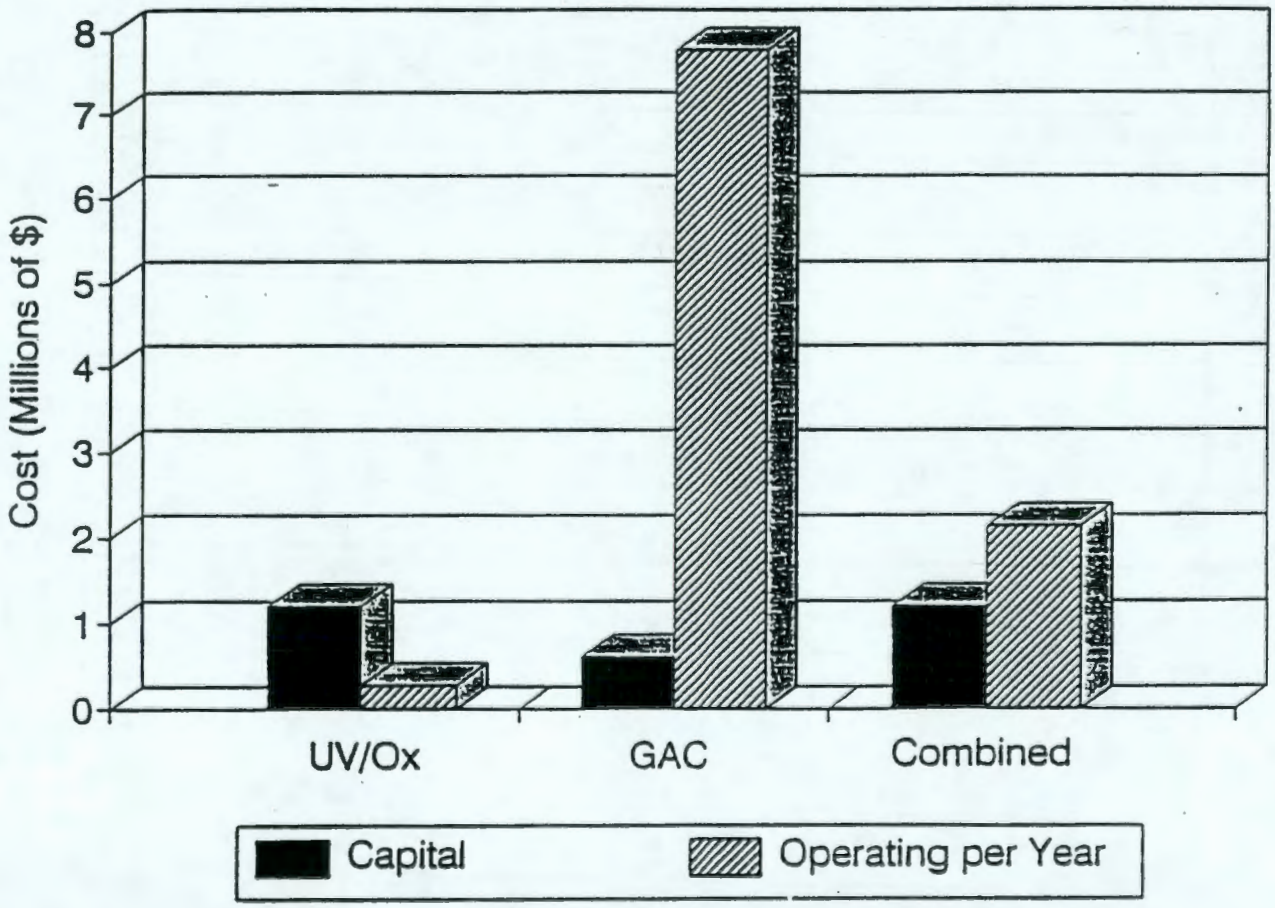
Capital and Operating Cost Comparison



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COST COMPARISON

	UV/OX	GAC
Single System		
Capital	$ 1,200,000	$ 600,000
Operating/yr.		
Power	145,000	
Chemical	100,000	780,000
Storage, Container, Labor*	30,000	7,000,000
TOTAL	$ 275,000	$ 7,780,000
Combined System		
Capital	600,000	600,000
Operating		
Power	72,500	
Chemicals	100,000	195,000
Storage, Container, Labor*	15,000	1,750,000
TOTAL	$ 187,500	$ 1,945,000

*GAC cost is estimated at $2,500/drum ($336/ft^3)

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Date: 02/19/93
Job Code: 0-6880-01
Letter No.: L-JPO/KEH-0254
Project Name: K-ETF
Contract No.: KEH-5232 (C-018H)

Mr. Karl D. Rickenbach
Area Contract Manager
Kaiser Engineers Hanford Company
Post Office Box 888
Richland, WA 99352

Subject: Close-out of D.O. #22

Dear Mr. Rickenbach:

The attached pages were not included in the transmittal of the report for the close-out of Delivery Order 22. The four pages are copies of the last four O/H slides presented to the Washington Department of Ecology on February 11, 1993.

Sincerely,

E.F. Holton, Jr.
Project Manager

EFH/rls

The decreasing contaminant level should usually provide for lower usage rates, but this has not been totally seen as yet. As the contaminant level decreases, the capacity of carbon for the contaminant also decreases according to the isotherm correlation. As the contaminants re-equilibrate in the carbon bed, the usage rate will increase over that which might be expected.

The presence of the less well adsorbed species, such as 1,1 and 1,2-dichloroethane, also skew the usage results as they will break through more rapidly than TCE and DCE. In fact, the results show that as dichloroethane is detected in the system effluent, the first stage is still effectively removing the relatively more strongly adsorbed trichloroethylene.

Overall, the carbon adsorption system has continued to provide effective treatment under changing conditions of variable contaminant levels and variable flow rates.

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OPERATING COST EVALUATION

The on-going system operating cost before tax consideration for Watkins-Johnson can be evaluated using both estimated and actual expenditures from 1989 (maintenance and manpower costs are estimated):

	Extraction & Pumping	Monitoring Requirements	GAC Treatment	TOTAL
Cost of Capital:	$32,280	--	$21,520	$ 53,800
Maintenance:	$14,000	--	$ 6,000	$ 20,000
Energy Costs:	$23,700	--	--	$ 23,700
Monitoring Costs:	--	$13,400	--	$ 13,400
Manpower Costs:	$ 3,000	$ 6,000	$ 2,000	$ 11,000
GAC Replacement:	--	--	$51,200	$ 51,200
Annual Cost:	$72,980	$19,400	$80,720	$173,100
Cost/1,000 Gal. Treated	$ 0.65	$ 0.17	$ 0.71	$ 1.53

The operating costs presented here reflect the entire treatment system, including all extraction wells and monitoring requirements. Costs are based upon the actual volume of water treated during 1989, which totaled 113 million gallons.

The energy costs (7.2¢/KWH) are based upon the four extraction wells at 7½ HP, 10 HP, 5 HP and 1 HP, and the transfer pump from the collection tank at 15 HP. The monitoring costs reflect samples from each well once per quarter and weekly samples at the system influent, midpoint, effluent and Bean Creek discharge (per NPDES). All samples are tested per EPA method 601. Manpower costs reflect 1 hr./day at $30/hr., which is primarily used for collecting samples. The GAC replacement costs reflect removal of spent carbon manifested per RCRA regulations and reactivation before any reuse and recharging the adsorber with 20,000 lbs. of virgin grade GAC.

The operating costs of the GAC treatment system are slightly higher than might be expected if the system economics were developed using the design example procedure; however, the breakthrough has been influenced by the presence of less well adsorbed contaminants and a fluctuating influent contaminant level.

SUMMARY OF OPERATION

In review, Watkins-Johnson has obtained a simple, cost-effective treatment scheme that has provided reliable water treatment for over three years. The system has even allowed use of the treated water in the plant for potable and other uses. The system is expected to provide trouble-free operation for years to come.

The GAC treatment system has allowed Watkins-Johnson to use a single treatment process to treat their groundwater. The GAC treatment system expends only 46% of the total treatment costs, and passes on more savings due to low maintenance and requiring little operator attention beyond monitoring.

CONCLUSION

Adsorption with granular activated carbon has proven to be a reliable and cost-effective means for groundwater remediation efforts. There are historical data bases and successful case studies to provide a basis for evaluation of the adsorption process. The procedure presented here, along with the Watkins-Johnson experience, will hopefully be a point of reference to evaluate other viable treatment technologies and serve as a planning technique for the successful application of activated carbon adsorption.

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FIGURE 1

SINGLE COMPONENT
ACTIVATED CARBON ADSORPTION ISOTHERMS

(1) Tetrachloroethylene
(2) M Xylene
(3) Toluene
(4) Trichloroethylene
(5) Benzene
(6) Cis 1,2 Dichloroethylene
(7) Chloroform
(8) 1,2 Dichloroethane

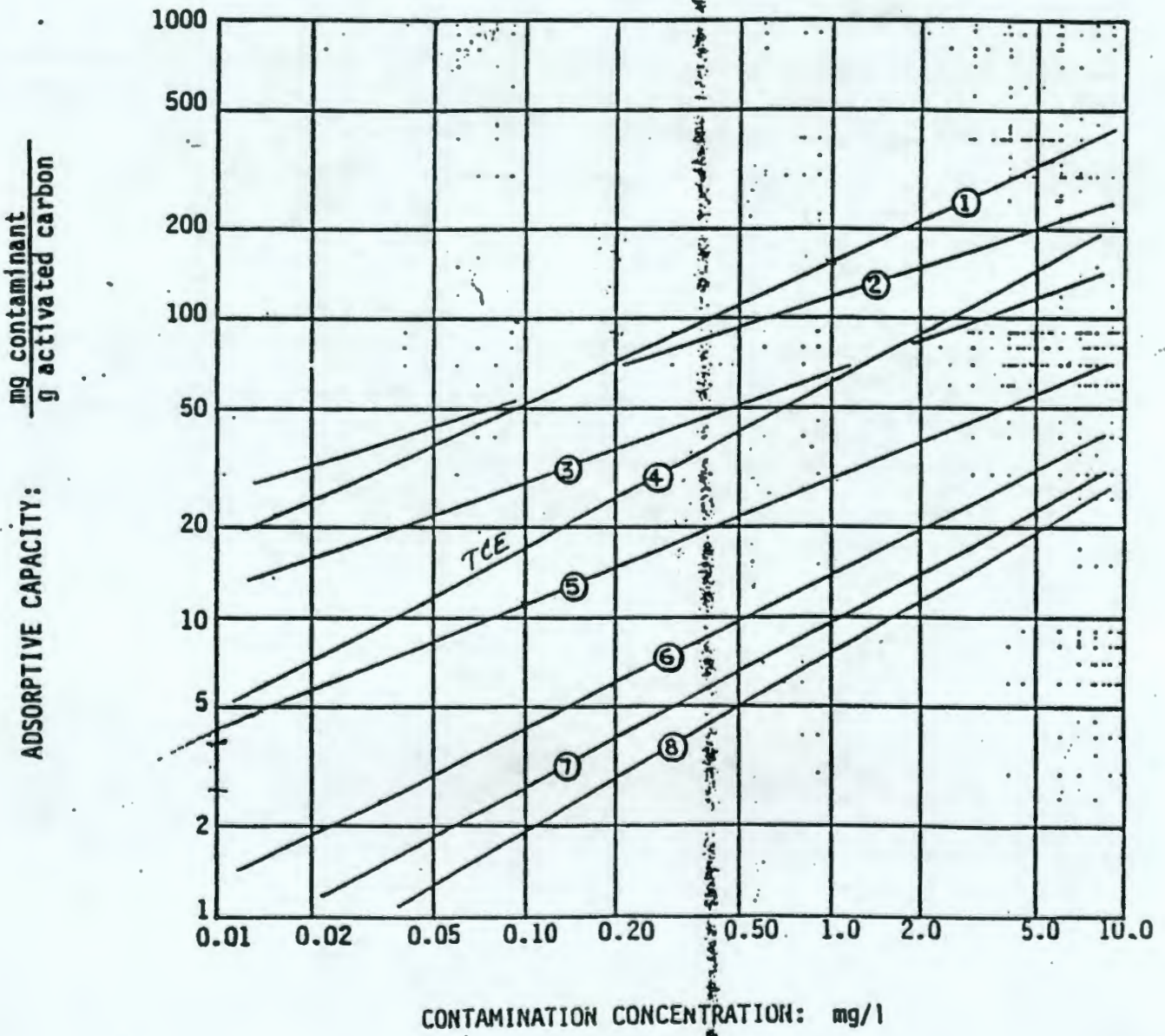

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FIGURE 2

ACCELERTED COLUMN TEST STUDIES
LOW LEVEL/SINGLE CONTAMINANT CASES

SITE:	MUNICIPAL GROUNDWATER	SYNTHETIC GROUNDWATER	SYNTHETIC GROUNDWATER	MUNICIPAL GROUNDWATER
CONTAMINANT	TRICHLOROETHYLENE	TRICHLOROETHYLENE	TRICHLOROETHANE	CHLOROFORM
CONCENTRATION, ppb	30	202	205	126
EFFLUENT OBJECTIVE, ppb	1	1	1	1
CONTACT TIME, minutes	10	8.5	8.5	12
GAC USAGE RATE, pounds/1000 gals.	0.07	0.12	0.36	0.9
REALIZED CAPACITY mg/gm	3.6	14.1	4.8	1.2
ISOTHERM (EQUILIBRIUM) CAPACITY, mg/gm	8.0	27.0	8.8	2.6
PERCENT OF EQUILIBRIUM CAPACITY REALIZED	45%	52%	54.5%	46%

FIGURE 3

ACCELERATED COLUMN TEST STUDIES
GROUNDWATER FROM REMEDIATION SITES (ACTUAL SITE SAMPLES)

	SIMULATED CONDITIONS		ADSORBATES		AT BREAKTHROUGH		SATURATION	
CASE	Loading gpm/sf	Contact Time Min.	Contaminant (Order of breakthrough)	Concentration mg/l	GAC Load mg/gm	Lbs/1000 Gallons	Effluent Conc. mg/l	Lbs/1000 Gallons
1	2.0	35	Benzene	0.024	0.5	0.4	0.002	—
			Toluene	0.116	2.4	0.4	0.002	—
			Xylene	0.630	13	0.4	0.001	—
2	3.8	20	1,2-Dichloroethane	0.095	0.13	5.9	0.003	4.0
			Chloroform	0.223	0.37	5	0.010	4.0
			Carbon Tetrachloride	3.08	6.4	4	0.010	—
3	1.3	100	Benzene	0.034	3.1	3.0	0.003	2.0
			Toluene	4.6	79.0	3.0	0.125	2.1
			Xylene	4.1	—	—	—	—
4	3.8	20	Chloroform	0.135	1.0	1.1	—	—
			Total Organic Carbon	6.0				

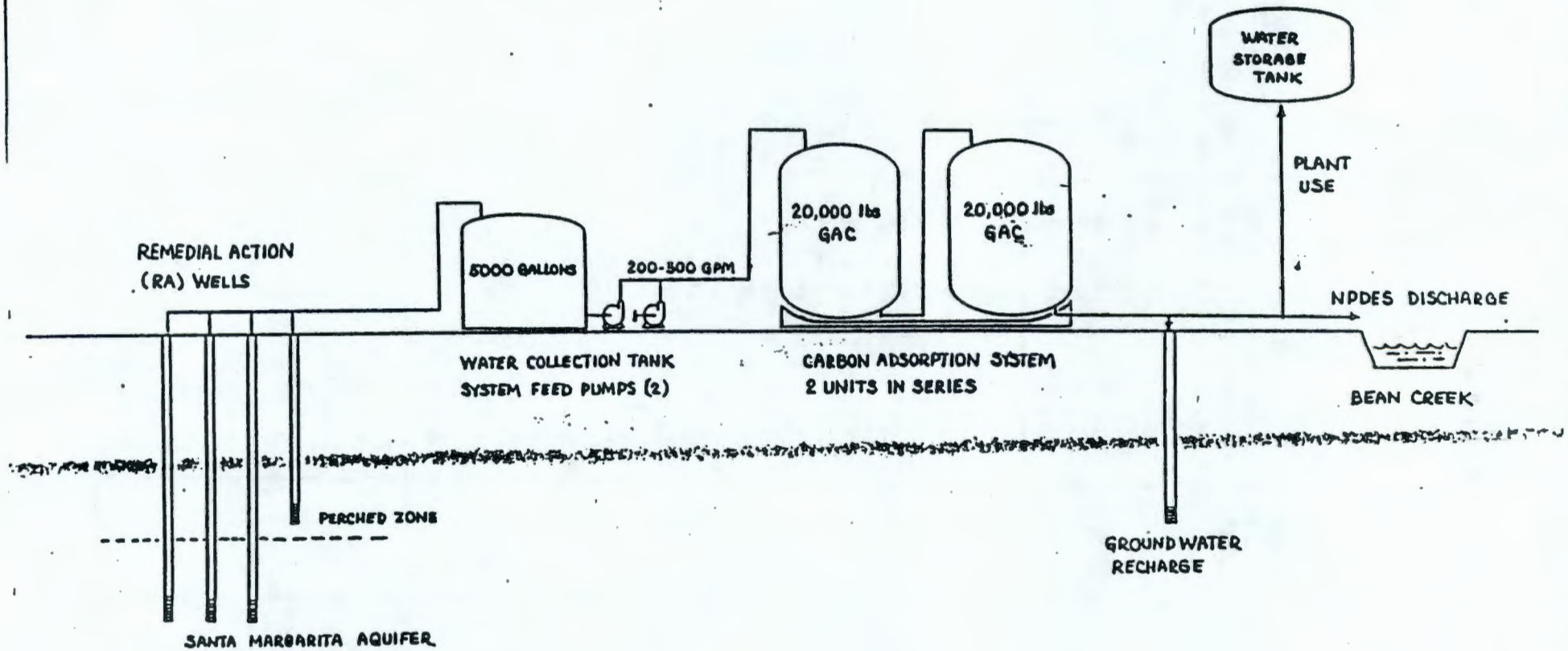

FIGURE 4

WATKINS-JOHNSON COMPANY

REMEDIAL ACTION FLOW SCHEMATIC

FIGURE 5

WATKINS-JOHNSON OPERATING RESULTS

OPERATING PERIOD	MILLION GALLONS TREATED	INFLUENT CONTAMINANT COMPOUND	INFLUENT CONCENTRATION CONC – µg/l	EFFLUENT CONTAMINANT COMPOUND	EFFLUENT BREAKTHROUGH CONC – µg/l	CARBON USE LBS/1,000 GALS.
10/02/86 – 03/19/87 5 mo 17 da	67.8	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	120 – 150 9 – 17 2 – 5 ND – 2 ND – 3	1,1-DCA	1.3	0.30
03/19/87 – 08/28/87 5 mo 9 da	58.7	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	31 – 155 ND – 13 ND – 5 ND – 1 ND – 2	1,1-DCA	2.9	0.34
08/28/87 – 01/26/88 4 mo 25 da	53.3	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	14 – 91 2 – 4 ND – 2 ND – 1 ND – <2	1,1-DCA Chloroform	1.0 1.1	0.38
01/26/88 – 06/29/88 5 mo 3 da	52.5	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	14 – 30 ND – 2 ND – 1 ND – ND ND – 2	1,1-DCA 1,2-DCE	1.3 1.8	0.38
06/29/88 – 11/29/88 5 mo	47.7	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	15 – 39 ND – <2 ND – <1 ND – 1 ND – <1	1,1-DCA Chloroform	0.64 1.0	0.42
11/29/88 – 05/15/89 5 mo 16 da	52.5	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	17 – 53 ND – <2 ND – <1 ND – ND ND – ND	1,1-DCA	1.4	0.38
05/15/89 – 10/24/89 5 mo 9 da	50.1	TCE t1,2-DCE 1,1,1-TCA 1,1-DCA Chloroform	15 – 35 ND – 2 ND – <1 ND – <1 ND – ND	1,1-DCA	0.71	0.40

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Effect of Initial Concentration of a SOC in Natural Water on Its Adsorption by Activated Carbon

Issam N. Najm, Vernon L. Snoeyink, and Yves Richard

One of the main factors affecting the equilibrium capacity of activated carbon for synthetic organic chemicals (SOCs) in natural water is the presence of background organic matter (BOM). However, the initial SOC concentration also plays an important role in determining the capacity of the carbon. The objective of this study was to develop a means of quantifying the effect of initial SOC concentration in different types of waters on its adsorption isotherm. The method used approximates the complex mixture of BOM with a single equivalent background compound (EBC). The initial concentration and single-solute isotherm constants of the EBC were calculated based on the BOM's competitive effect on the adsorption of the SOC on activated carbon. The EBC method was then successfully used to predict the equilibrium capacity of powdered activated carbon for 2,4,6-trichlorophenol in several natural and finished waters when present at different initial concentrations.

With the enactment of the 1986 amendments to the Safe Drinking Water Act,[1] the control of organic contaminants in drinking water supplies has become a major concern for many water utilities. The United States Congress specified that granular activated carbon (GAC) is the best available technology (BAT) for the control of a vast majority of synthetic organic chemicals (SOCs).[1] Powdered activated carbon (PAC) is widely used to control taste and odor problems[2,3] and can also be applied for the removal of SOCs, although it has not been designated as BAT.[4,5]

To evaluate the performance of activated carbon for the adsorption of organic compounds, the equilibrium capacity of the carbon must be determined. A

A full report of this project, entitled "Control of Organic Compounds With Powdered Activated Carbon" (catalog no. 90581), is available from the AWWA Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235.

TABLE 1

Characteristics of tap water, Jefferson Parish water, Lake Decatur water, and groundwater

Component	Tap Water	Jefferson Parish Water	Lake Decatur Water	Groundwater
DOC—*mg/L*	1.2	3–4	3.5	3.0
pH	8.5–9.0	7.5	8.0	7.3
Alkalinity—*mg/L as* $CaCO_3$	100–125	85	200	290
Ca^{2+}—*mg/L*	14	41	64	60.1
Mg^{2+}—*mg/L*	11	12	26.6	38.2
Hardness—*mg/L as* $CaCO_3$	80	151	260	307

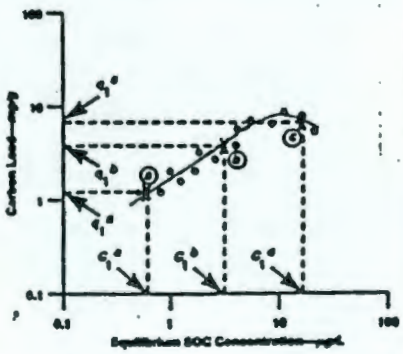

Figure 1. Schematic representation of the procedure for solving for the EBC characteristics

TABLE 2
Manufacturers' analyses of PACs

Parameter	Adsorbent A*	Adsorbent B†
Iodine number—*mg/g*	1,199	600
Moisture as packed—*percent*	3	5
Apparent density—*g/cm³*	0.54	0.74
Ash content—*percent*	6	
Passing 100 mesh—*percent*		99
Passing 200 mesh—*percent*		97
Passing 325 mesh—*percent*	98	90
Base material	Coal	Coal

*WPH PAC, Calgon Carbon Corp., Pittsburgh, Pa.
†Aqua PAC, Westvaco, Covington, W.Va.

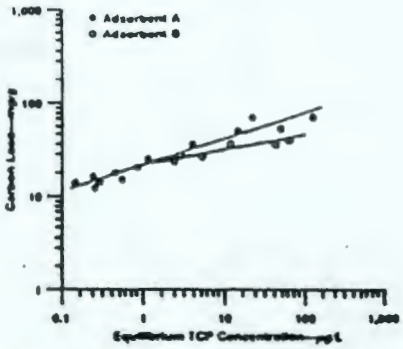

Figure 2. Adsorption of TCP on adsorbents A and B from distilled–deionized water

main factor affecting the equilibrium capacity of activated carbon for SOCs in natural water is the presence of background organic matter (BOM). BOM competes with the target SOC for adsorption sites, thus reducing the capacity of the carbon for the SOC. Several workers have reported lower capacities of activated carbon for SOCs in natural water than when present in distilled–deionized water.[6-9] Any increase in the BOM concentration causes a further decrease in the carbon capacity for the target SOC.

The initial SOC concentration, however, also plays an important role in determining the capacity of activated carbon. For a constant BOM concentration, a decrease in the initial SOC concentration decreases the equilibrium capacity of the carbon for that SOC. An example of this effect was reported by Frick et al.,[10] who found that the equilibrium capacity of activated carbon for *p*-nitrophenol (PNP) decreased with decreasing initial PNP concentration in the presence of 10 mg/L lignin sulfonic acid (LSA) in an isotherm experiment. This behavior is due to competition between the LSA and the PNP for adsorption onto the carbon surface. Although the adsorption isotherm of a SOC from natural or finished water is dependent on the initial SOC concentration, the SOC isotherm from distilled water free of BOM is not a function of initial concentration. The objective of this study was to develop a means of quantifying the effect of initial SOC concentration in different types of waters on its adsorption isotherm.

The ideal adsorbed solution theory (IAST) was used in this study to describe the competitive adsorption between BOM and a SOC. The IAST was first developed by Myers and Prausnitz[11] to describe adsorption of gases onto solid surfaces and was then extended by Radke and Prausnitz[12] to describe adsorption from aqueous solutions. When used to describe the equilibrium capacity of activated carbon for organic compounds from multisolute systems, the IAST requires knowledge of the single-solute isotherm parameters of each of the solutes, as well as their initial concentrations. However, during the adsorption of a SOC onto activated carbon from natural water, the competing solute for adsorption is the BOM, which is a heterogeneous mixture of organic compounds of different types, molecular sizes, and strengths of adsorption. This complicates the use of the IAST to describe the adsorption of the SOC. Several researchers have attempted to represent the BOM by a mixture of fictive components of different initial concentrations, $C_{i,o}$, and Freundlich isotherm constants, K_i and $1/n_i$. The division of BOM into fictive components was first proposed by Frick[13] for the adsorption of organic compounds from unknown mixtures. Several researchers have used the fictive component approach to describe the competitive effect of BOM on the adsorption of SOCs from waters of unknown compositions.[10,14] The details of this approach, which were discussed by Sontheimer et al.,[6] can be summarized as follows:

- an adsorption isotherm of the SOC is conducted in distilled–deionized water, and the single-solute Freundlich isotherm constants K and $1/n$ of the SOC are determined from that isotherm;
- an isotherm of the SOC is conducted in the natural water; and
- the IAST and the previous two isotherms are used to search for the number of fictive components, along with their respective initial concentrations, $C_{i,o}$, and Freundlich constants, K_i and $1/n_i$. The search is conducted by minimizing the error between the experimental data of the SOC natural water isotherm (step 2) and the predicted equilibrium values.

The main disadvantage of this approach is that it requires substantial computer programming skills. The computer search for the values of the different parameters requires the use of optimization algorithms such as those found in the International Mathematics and Statistics Library. Furthermore, the solution of the problem is further complicated when the number of fictive components is increased.

A modification of the procedure is presented in this article. This modification attempts to represent the BOM, which includes the natural organic matter and any other organics present, by a single compound that is referred to as the equivalent background compound (EBC). The characteristics of the EBC are determined by the magnitude of the competitive effect of the BOM and not by its dissolved organic carbon (DOC) isotherm. The modified procedure described here requires substantially less computer programming because minimization of the error between the experimental data and the mathematical prediction is not required.

EBC method

The BOM present in the natural and finished waters used in this study was represented by a single compound—the EBC—with an unknown initial concentration C_o and Freundlich isotherm parameters K and $1/n$. The SOC solution in groundwater was therefore reduced to a bisolute system with the SOC labeled as compound 1 and the EBC labeled as compound 2.

For a bisolute system, the IAST equations used to determine the equilibrium surface concentrations of the two solutes q_1 and q_2 are[6,14]

$$F_1 = C_{L,o} - C_{e1} - \left(\frac{q_1}{q_1 + q_2}\right)\left[\frac{n_1 q_1 + n_2 q_2}{n_1 K_1}\right]^{n_1} = 0 \qquad (1)$$

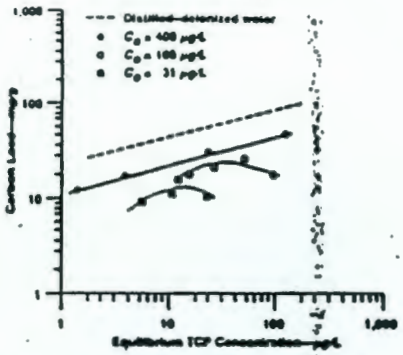

Figure 3. Effect of initial concentration of TCP in groundwater on its isotherm on adsorbent A

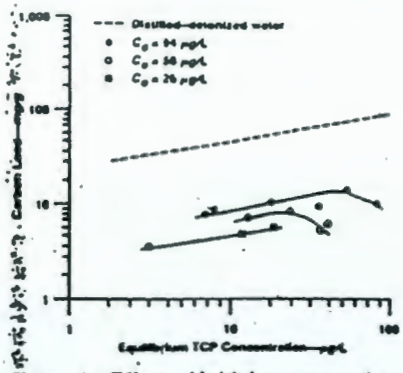

Figure 4. Effect of initial concentration of TCP in Lake Decatur water on its isotherm on adsorbent A

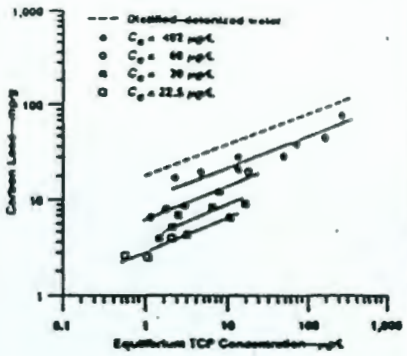

Figure 5. Effect of initial concentration of TCP in Jefferson Parish water on its isotherm on adsorbent A

$$F_2 = C_{2,o} - C_c q_2 - \left(\frac{q_2}{q_1 + q_2}\right)\left[\frac{n_1 q_1 + n_2 q_2}{n_2 K_2}\right]^{n_2} = 0 \quad (2)$$

Given the single-solute parameters K_1, K_2, $1/n_1$, and $1/n_2$ and the initial concentrations $C_{1,o}$ and $C_{2,o}$, the previous two nonlinear functions can be simultaneously solved to determine the values of q_1 and q_2 for a given carbon dosage C_c. However, the values of K_2, $1/n_2$, and $C_{2,o}$ of the EBC (which are collectively referred to as the EBC characteristics) are not known. The authors propose that the following procedure be used to obtain the EBC characteristics, which can then be incorporated into the IAST to determine the equilibrium capacity of PAC for a SOC present in natural water at any initial concentration. The procedure makes use of the SOC single-solute Freundlich isotherm, as well as one set of SOC equilibrium data for adsorption from natural water (a schematic of the procedure is shown in Figure 1).

- The single-solute isotherm of the SOC is conducted in distilled–deionized water, and the values of K_1 and $1/n_1$ are determined.
- A bottle-point isotherm is conducted for the adsorption of the SOC from natural water using a known initial concentration, $C_{1,o}$.
- Three distinct equilibrium points, denoted by the letters *a*, *b*, and *c*, are chosen from the line of best fit to the isotherm determined in step 2 (see Figure 1). The equilibrium points are chosen so as to cover a wide range of that isotherm. The values of the liquid and surface concentrations at points *a*, C_1^a, and q_1^a, respectively, as well as at points *b* and *c*, C_1^b, q_1^b, C_1^c, and q_1^c, are graphically determined. By using the initial SOC concentration $C_{1,o}$ in the isotherm test, it is possible to calculate the carbon dosages for each of the three points C_c^a, C_c^b, and C_c^c, by the following equations:

$$C_c^a = \left(\frac{C_{1,o} - C_1^a}{q_1^a}\right) \quad (3)$$

$$C_c^b = \left(\frac{C_{1,o} - C_1^b}{q_1^b}\right) \quad (4)$$

$$C_c^c = \left(\frac{C_{1,o} - C_1^c}{q_1^c}\right) \quad (5)$$

- Each SOC surface concentration and calculated carbon dosage, q_1^a and C_c^a, q_1^b and C_c^b, and q_1^c and C_c^c, in this step are then substituted into Eqs 1 and 2 to give a distinct pair of functions, F_1 and F_2. Therefore, using the three pairs of q_1 and C_c determined, six nonlinear functions are obtained:

$$F_1^a = C_{1,o} - C_c^a q_1^a - \left(\frac{q_1^a}{q_1^a + q_2^a}\right)\left[\frac{n_1 q_1^a + n_2 q_2^a}{n_1 K_1}\right]^{n_1} = 0 \quad (6)$$

$$F_2^a = C_{2,o} - C_c^a q_2^a - \left(\frac{q_1^a}{q_1^a + q_2^a}\right)\left[\frac{n_1 q_1^a + n_2 q_2^a}{n_2 K_2}\right]^{n_2} = 0 \quad (7)$$

$$F_1^b = C_{1,o} - C_c^b q_1^b - \left(\frac{q_1^b}{q_1^b + q_2^b}\right)\left[\frac{n_1 q_1^b + n_2 q_2^b}{n_1 K_1}\right]^{n_1} = 0 \quad (8)$$

$$F_2^b = C_{2,o} - C_c^b q_2^b - \left(\frac{q_1^b}{q_1^b + q_2^b}\right)\left[\frac{n_1 q_1^b + n_2 q_2^b}{n_2 K_2}\right]^{n_2} = 0 \quad (9)$$

$$F_1^c = C_{1,o} - C_c^c q_1^c - \left(\frac{q_1^c}{q_1^c + q_2^c}\right)\left[\frac{n_1 q_1^c + n_2 q_2^c}{n_1 K_1}\right]^{n_1} = 0 \quad (10)$$

$$F_2^c = C_{2,o} - C_c^c q_2^c - \left(\frac{q_1^c}{q_1^c + q_2^c}\right)\left[\frac{n_1 q_1^c + n_2 q_2^c}{n_2 K_2}\right]^{n_2} = 0 \quad (11)$$

In these six functions, the values of $C_{1,o}$, K_2, n_1, C_c^a, C_c^b, C_c^c, q_1^a, q_1^b, and q_1^c are known. The six functions are then simultaneously solved for the six unknowns: $C_{2,o}$, K_2, n_2, q_2^a, q_2^b, and q_2^c for the EBC.

The values of the EBC characteristics, $C_{2,o}$, K_2, and $1/n_2$, were then substituted in Eqs 1 and 2 to determine the equilibrium capacity of PAC for SOC for any initial concentration $C_{1,o}$ and carbon dosage C_c.

Materials

Adsorbate. The representative SOC used in this study was reagent-grade 2,4,6-trichlorophenol (TCP),* a soluble, nonvolatile, chlorinated aromatic compound. Reagent-grade 2,4-dichlorophenol (DCP)* was added to all TCP samples as an internal standard at a concentration of 100 µg/L. Stock solutions of TCP and DCP were prepared by weighing dry amounts of the compounds and dissolving them in distilled–deionized water. All solutions were refrigerated when not in use.

Water sources. Several types of waters were used in this study, including (1) untreated central Illinois groundwater, (2) Lake Decatur water (a central Illinois surface water reservoir), (3) central Illinois tap water, and (4) clarified Jefferson Parish, La., water. The characteristics of the four waters are listed in Table 1.

Adsorbents. The adsorbents used in this study were coal-based PACs.† The manufacturers' analyses of the carbons are listed in Table 2.

Methods

Experiments. Isotherm adsorption tests of TCP on PAC were conducted using the bottle-point technique. High-concentration TCP isotherms (C_o > 300 µg/L) were conducted by adding 100-mL volumes of a TCP solution to 160-mL glass bottles containing different masses of PAC. Bottles were then covered with PTFE-lined rubber septa‡ and sealed with aluminum

*Eastman Kodak Co., Rochester, N.Y.
†Adsorbent A—WPH PAC, Calgon Carbon Corp., Pittsburgh, Pa; adsorbent B—Aqua PAC, Westvaco Corp., Covington, W.Va.
‡Wheaton, Millville, N.J.

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TABLE 3

EBC characteristics describing the competitive effect of NOM on the adsorption of TCP by PAC

Water Source	PAC Type	C_e µg/L	K (mg/g)(µg/L)$^{-1/n}$	$1/n$
Groundwater	Adsorbent A	3,535	0.417	0.82
Jefferson Parish Water	Adsorbent A	5,100	0.026	1.20
Lake Decatur water	Adsorbent A	3,000	4.880	0.57
Tap water	Adsorbent B	785	16.45	0.30

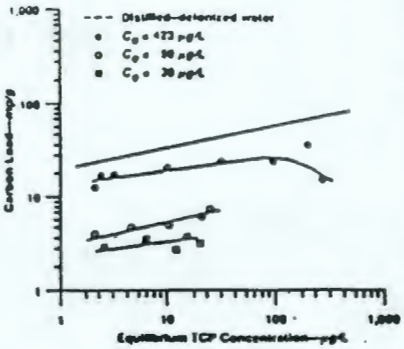

Figure 6. Effect of initial concentration of TCP in tap water on its isotherm on adsorbent B

caps. Lower-concentration TCP isotherms were conducted by adding 500-mL volumes of TCP solutions to 800-mL glass bottles. Bottles were then put on a shaker in the dark. TCP isotherms were incubated for more than four days. After equilibrium was reached, samples were withdrawn with gas-tight glass syringes* and were filtered through 0.22-µm nylon membrane filters.†

Analyses. TCP samples were extracted with toluene after adding 100 µg/L of 2,4-dichlorophenol as an internal standard. The extracted samples were then analyzed using a gas chromatograph‡ with a 6-ft packed-glass column§ and an electron capture detector (ECD).

Mathematical solution. To determine the values of $C_{2,e}$, K_2, and n_2 for the EBC, six nonlinear equations in six unknowns (Eqs 6–11) had to be simultaneously solved. When those values were obtained, a system of two equations in two unknowns (Eqs 1 and 2) was then solved to determine the equilibrium adsorption of TCP onto C_e mg PAC/L from natural water when present at an initial concentration $C_{1,e}$.

A software package, General INteractive Optimizer (GINO) developed by K. Cunningham,[15] was used in this study to solve each of the systems of nonlinear equations. GINO uses GRG2, a version of the Generalized Reduced Gr dient (GRG) algorithm, to solve the system of nonlinear equations by an unconstrained optimization technique.

Results and discussion

Single-solute isotherms. Figure 2 shows the Freundlich equation fit to the adsorption isotherms of TCP in distilled–deionized water on adsorbents A and B. The values of K and $1/n$ for the two types of carbon were surprisingly close to each other considering that the carbons have significantly different iodine numbers (Table 2). The Freundlich constants are also comparable to those determined by Dobbs et al[16] for TCP on granular activated carbon (GAC) at a pH value of 3 (K = 29 [mg/g][µg/L]$^{-1/n}$ and $1/n$ = 0.29).

TCP in natural and finished waters. *Effect of initial TCP concentration.* As discussed earlier, the SOC isotherm is strongly affected by the initial SOC concentration. To determine this effect, isotherm tests were conducted for the adsorption of TCP in three different types of water on adsorbent A. To eliminate any discrepancies resulting from variations in water characteristics, each of the series of isotherms was conducted by splitting the same batch of water. Figures 3–5 show the effect of initial TCP concentration on its adsorption isotherm on adsorbent A in groundwater, Lake Decatur water, and Jefferson Parish water, respectively. Figure 6 shows the effect of initial TCP concentration on the capacity of adsorbent B for TCP in central Illinois tap water. As shown in Figures 3–6, a decrease in the initial TCP concentration in the presence of BOM significantly decreases the capacity of activated carbon for TCP. For example, at a TCP equilibrium concentration of 1 µg/L in Jefferson Parish water, the carbon capacity for an isotherm conducted with 492 µg/L initial concentration is equal to 10 mg/g, whereas it reduces to 3 mg/g (70 percent reduction in capacity) in an isotherm conducted with 22.5 µg/L initial TCP concentration. It can therefore be concluded that in a continuous PAC process in which equilibrium is reached, the carbon usage rate for a low influent SOC concentration can be significantly higher than that suggested by an equilibrium isotherm conducted with a higher initial SOC concentration.

Application of the EBC method. Using the proposed EBC method, a single isotherm from each of Figures 3–6 was used to solve the initial concentration $C_{2,e}$ and the Freundlich constants K_2 and $1/n_2$ of the EBC for the water in which the TCP isotherm was conducted. Following the EBC procedure presented here, the 400-µg/L isotherm, the 69-µg/L isotherm, and the 94-µg/L isotherm were used to calculate the EBC characteristics of the groundwater, Jefferson Parish water, and Lake Decatur water, respectively, for adsorption on adsorbent A. The values of the initial concentrations were arbitrarily chosen subject to the constraint that there is an appreciable difference in capacity between the distilled water isotherm and the natural water isotherm. Similarly, the 50-µg/L isotherm was used to determine the EBC characteristics of tap water for the adsorption of TCP on adsorbent B. Table 3 summarizes the EBC characteristics determined for each of the waters tested. Figure 7 shows the IAST fit to the isotherms using the EBC characteristics listed in Table 3.

It should be emphasized that the EBC characteristics determined by this method for a certain water are not necessarily unique. Different combinations of $C_{2,e}$, K_2, and $1/n_2$ can represent the same water, resulting in the same competitive effect on the adsorption of an SOC on activated carbon from that water. As an example, Figure 8 shows the IAST prediction for the equilibrium adsorption of 100 µg TCP/L from Lake Decatur water using three different EBC characteristics. Figure 8 shows that the competitive effect of BOM on the adsorption of TCP using any of the three combinations is virtually the same.

Application of the IAST. The IAST was then used to predict the equilibrium ad-

*Hamilton Co., Reno, Nev.
†Magna, Westborough, Mass.
‡Model 5890, Hewlett-Packard, Avondale, Calif.
§SS-1240 HA, 100/200 Supelcoport, Supelco Inc., Bellefonte, Pa.

sorption of TCP when present at different initial concentrations in the presence of BOM. The EBC characteristics determined (Table 3) were incorporated into the IAST model, which was used to predict the carbon capacity. The predictions were then compared with experimental data determined from bottle-point isotherms. Figure 9 shows the comparison between experimental data and the IAST prediction for TCP adsorption from groundwater on adsorbent A for initial concentrations of 100 and 31 µg/L. Figure 10 shows a comparison between the IAST prediction and the experimental data for the 50- and 26-µg/L TCP adsorption isotherms with adsorbent A and Lake Decatur water. Figure 11 shows a comparison between the IAST prediction and the experimental data for the 22.5-, 39-, and 492-µg/L TCP adsorption isotherms with adsorbent A and Jefferson Parish water. And finally, Figure 12 shows a comparison between the IAST prediction and the experimental data for the 30- and 423-µg/L adsorption isotherms with adsorbent B and tap water.

Most of the predictions in Figures 9 through 12 accurately describe the experimental data for the equilibrium adsorption of TCP. However, some predictions do not. Specifically, the 492-µg/L isotherm in Jefferson Parish water was poorly predicted by the proposed method (Figure 11), as was the 26-µg/L isotherm in Decatur water (Figure 10). At present, there is no explanation for this behavior. Further research into the applicability and limitations of the EBC method is necessary before any firm conclusions can be made. Considering the heterogeneity of the BOM in natural waters, its representation by a single compound is not always expected to accurately describe its competitive effect on the adsorption of an SOC. However, the simplicity of the EBC method and its fair representation of the experimental data determined in this study favor its use in describing that effect.

The isotherm data that are shown in Figure 9 indicate a deviation from the linear Freundlich equation at equilibrium concentrations close to the initial concentration C_o. The IAST predictions in Figure 9, which use the EBC characteristics from Table 3, do not show that behavior. This curvature of the isotherm has been reported by other researchers for the adsorption of SOCs in natural waters.[6,12] This behavior is commonly attributed to the competitive adsorption of a fraction of the BOM that is more adsorbable than TCP on the PAC. The reason the predicted isotherm in Figure 9 does not show this curvature is that the EBC characteristics used to make the predictions were determined from a set of equilibrium data that did not extend to the curved part of the isotherm (Figure 7).

The applicability of the EBC approach was further tested using the data of Baldauf[9] and Haist-Gulde et al[17] for the equilibrium adsorption of the herbicide metazachlor on activated carbon in the presence of 0.3 mg/L background DOC. Figure 13 shows the EBC–IAST fit to the equilibrium isotherm data conducted with an initial metazachlor concentration of 60 µg/L. The calculated EBC characteristics that are listed in Figure 13 were

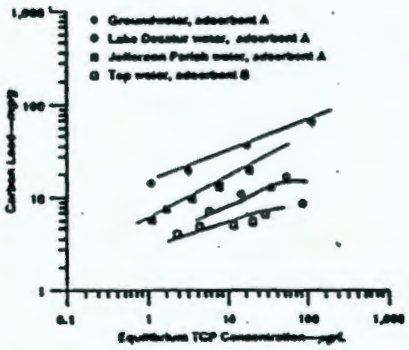

Figure 7. EBC–IAST fit to the adsorption isotherm of TCP on PAC

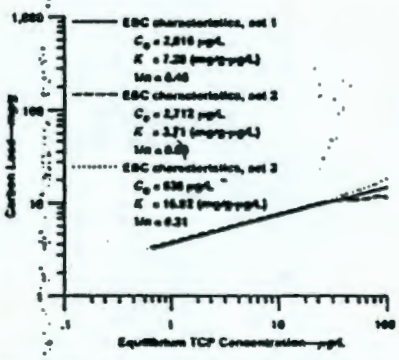

Figure 8. Comparison of the prediction of three sets of EBC characteristics for the adsorption of 100 µg TCP/L on adsorbent A

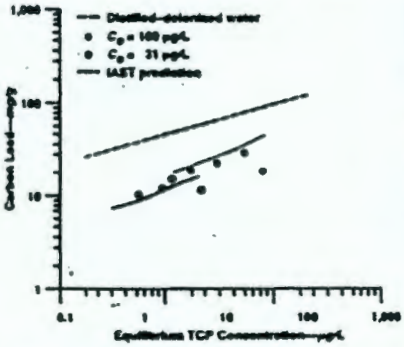

Figure 9. Comparison of the IAST prediction with the experimental data for the adsorption of TCP in groundwater on adsorbent A

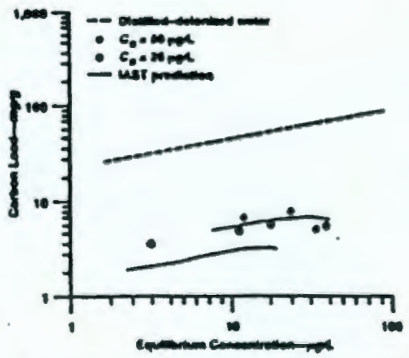

Figure 10. Comparison of the IAST prediction with the experimental data for the adsorption of TCP in Lake Decatur water on adsorbent A

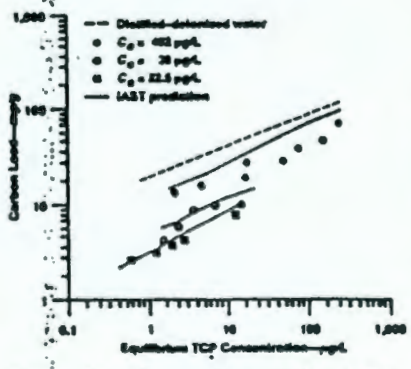

Figure 11. Comparison of the IAST prediction with the experimental data for the adsorption of TCP in Jefferson Parish water on absorbent A

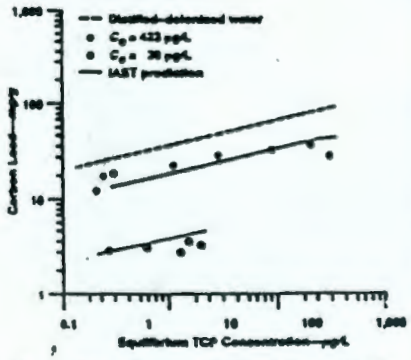

Figure 12. Comparison of the IAST prediction with the experimental data for the adsorption of TCP in central Illinois tap water on adsorbent B

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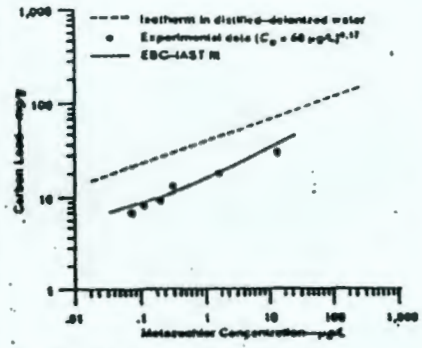

Figure 13. EBC–IAST fit to the adsorption isotherm of metazachlor on PAC *(EBC characteristics: $C_{2,0}$—1,103 µg/L; K_2—3.57 [mg/g·µg/L]; $1/n_2$—0.706)*

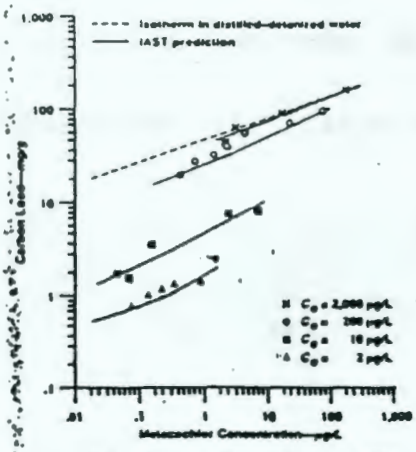

Figure 14. Comparison of the IAST prediction with the experimental data for the adsorption of metazachlor in the presence of 0.3 mg DOC/L[9,17]

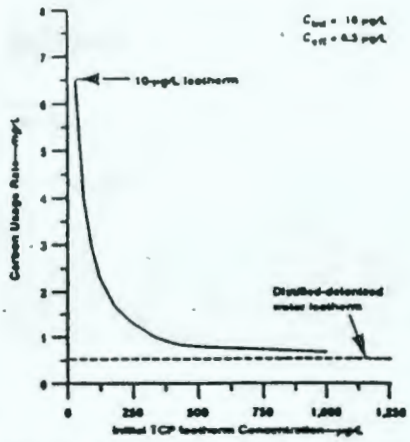

Figure 15. Effect of initial TCP isotherm concentration on the calculated carbon usage rate required for the reduction of 10 µg TCP/L to 0.5 µg/L in groundwater

then used to predict the isotherm capacities of activated carbon for metazachlor when present at initial concentrations of 2, 10, 200, and 2,000 µg/L. Figure 14 shows the comparison between the IAST predictions and the experimental data. Figure 14 clearly shows that the EBC approach well predicts the isotherm capacities of activated carbons for SOCs present in natural waters at any initial concentration.

The EBC method can also be used when the BOM is represented by more than one compound. To account for the added variable to be calculated (mainly the initial concentration and Freundlich constants of the additional representative compounds), more than three points on the best fit of the isotherm data should be taken (Figure 1). For representing the BOM by two compounds, six equilibrium points have to be selected, which increases the number of equations to be solved (and thus the number of unknowns) to 18. Representing the BOM by three compounds requires nine equilibrium points and the solution of 36 simultaneous equations in 36 unknowns. In general, the number of equilibrium points, N, is equal to three times the number of representative compounds, M, and thus the number of equations to be solved is equal to $N(M + 1)$.

Effect on carbon usage rate. The reduction of equilibrium carbon capacity with decreasing initial SOC concentration has serious implications for the estimation of activated carbon usage rates for drinking water treatment. Virtually all SOC adsorption isotherms from natural waters presented in the literature were conducted with very high initial SOC concentrations to improve analytical accuracy and to cover a wide equilibrium concentration range. However, in full-scale processes, the influent SOC concentration almost never exceeds 10 to 20 µg/L. Therefore, if an adsorption isotherm conducted with a 500- to 1,000-µg/L initial concentration of SOC was used to calculate the carbon usage rate required to achieve the reduction of the SOC concentration to a certain target effluent value, the dosage would be significantly underestimated.

Effect on PAC dosage. Figure 15 is an example plot of the dosage of adsorbent A necessary to reduce the concentration of TCP in groundwater from 10 µg/L to an equilibrium concentration of 0.5 µg/L, as predicted by isotherms conducted with different initial concentrations. The EBC characteristics of the groundwater listed in Table 3 were used to develop the plot in Figure 15. This figure shows that an isotherm conducted with a C_o of 500 µg TCP/L leads to the prediction that a carbon dosage of 1 mg/L is required to reduce the concentration of TCP in groundwater from 10 to 0.5 µg/L. However, an isotherm conducted with a C_o of 10 µg/L leads to the prediction that a carbon dosage of 6.5 mg/L is required for the same removal. These results show that to fairly estimate the carbon usage rate for a continuous PAC process, the bench-scale adsorption isotherm should be conducted with an initial concentration comparable to that in the influent water to the continuous process, or that the procedure described above (EBC method) should be used to calculate this isotherm.

Miltner et al[7] investigated the occurrence of several pesticides and herbicides in the Ohio River. They reported that the capacity of PAC for alachlor in jar tests was one order of magnitude lower than the equilibrium isotherm values. This large difference was attributed to possible lack of contact time or to interference from treatment chemicals. However, the initial concentrations used in the jar tests (25.6 and 43.6 µg/L) were far lower than that used in conducting the equilibrium isotherm of alachlor from Ohio River water (440 µg/L).[16] Using the reported isotherms of alachlor on activated carbon in distilled–deionized water and Ohio River water, the EBC method described here was used to determine the EBC characteristics of Ohio River water. The values of $C_{2,o}$, K_2, and $1/n_2$ were calculated at 38,035 µg/L, 0.378 (mg/g) (µg/L)$^{-1/n_2}$, and 0.836, respectively. The equilibrium isotherms were then determined for the adsorption of alachlor on PAC from Ohio River water when present at initial concentrations of 25.6 and 43.6 µg/L (Figure 16). Figure 16 shows a comparison between the PAC performance data for the removal of alachlor from Ohio River water in the jar tests and the IAST predictions using the EBC characteristics. The predicted isotherms for C_o values of 43.6 and 25.6 µg/L are much closer to the experimental data than the isotherm with a C_o of 440 µg/L but still indicate a somewhat higher capacity than was observed. Possible reasons for the differences observed include the fact that GAC was used for the distilled water isotherm whereas PAC was used for the jar tests, inaccuracy of model predictions, interference of alum with adsorption in the jar tests, and insufficient time for equilibrium to be reached in the 90-min jar test.[10] Baldauf[9] reported that the kinetics of pesticide adsorption at low concentration were very slow and that much more than 90 min may be required for equilibrium. Additional time for equilibrium can be achieved by adding PAC

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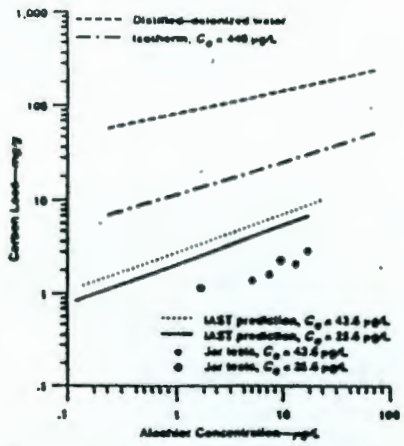

Figure 16. Effect of initial concentration of alachlor in Ohio River water on its adsorption isotherm

to an upflow floc-blanket clarifier[4] or a slurry recirculation clarifier.

Summary and conclusions

This study determined the competitive effect of BOM on the adsorption of SOCs on activated carbon. The findings of this research can be summarized as follows.

- Adsorption data indicate that the equilibrium isotherm of TCP on PAC in natural or finished water is highly dependent on the initial TCP concentration because of the competition of BOM for adsorption sites on the surface of the carbon. The equilibrium carbon capacity at a certain aqueous concentration decreases with decreasing initial SOC concentration in the isotherm test. As an example, the carbon capacity calculated using a 22.5-µg/L TCP isotherm on adsorbent A in Jefferson Parish water is 70 percent lower than that calculated using a 492-µg/L isotherm. The consequence of such a behavior is that isotherm data collected using high initial concentrations will highly underestimate the carbon dosage required for the reduction of lower SOC concentrations to certain equilibrium target values. As an example, based on a TCP isotherm conducted with an initial concentration of 500 µg TCP/L in groundwater, 1 mg PAC/L is required to reduce the concentration of TCP from 10 to 0.5 µg/L. However, based on an isotherm conducted with an initial concentration of 10 µg TCP/L, 6.5 mg PAC/L is required for the same removal. A comparable effect is expected for the adsorption of SOCs from natural water onto GAC.
- A simple method was used to determine the adsorption isotherm of TCP, when present in natural water at any initial concentration, on activated carbon. The method approximates the complex mixture of BOM with a single compound: the EBC. The initial concentration and single-solute isotherm constants of the EBC are calculated based on the BOM's competitive effect on the adsorption of the SOC on activated carbon.
- The EBC method was then successfully used to predict the equilibrium capacity of PAC for TCP present at different initial concentrations in several natural and finished waters.
- On the basis of these findings, when determining the PAC dosage required in a continuous PAC process to achieve a certain removal of a SOC from natural water, the isotherm to be used should be conducted with an initial SOC concentration equal to the concentration of the influent to the process. In the absence of such an isotherm, the EBC method can be used to predict the equilibrium capacity of PAC for that SOC when present at that initial concentration.

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Calculations for Cost Comparisons

I. UV/OX System

A. Capital = (2) **perox-pure™** Model 360s at the bid price including changes as of February 5, 1993

= $1,200,000

B. Operating/year

1. Power @ $0.04/kWh = 600 kW x 24 hr/day x 250 days/yr x $0.04/kWh

= $144,000/yr.

Notes: 600 kW is design basis from confirmation testing and bid specs. 250 days/yr operation is from design specifications.

2. Chemical @ $1.00/lb H_2O_2 as 100%

= 200 mg/l x 0.24 MG/day x 8.33* x 250 days/yr

= 100,000 lbs/yr x $1.00/lb

= $100,000/yr

Notes: 200 mg/l H_2O_2 is from confirmation tests and PSI bid.
* This conversion factor converts mg-MG/l-day to lbs/day

3. Storage, Container & Labor = $30,000

Notes: Taken from Adtechs design documents for disposal of lamps and quartz tubes.

II. GAC System

A. Capital = $600,000

Taken from two year old engineering report prepared by Westinghouse Hanford Corporation. Recent estimates prepared by KEH show about $700,000.

Notes: The equipment sizing and therefore capital cost is based on residence time at the design flow rate. Therefore, the capital cost is independent of carbon usage or the use of GAC after UV/OX.

B. Operating/yr.

1. Power @ $0.04/kWh = Assumed to be negligible for this comparison.

2. Chemical @ $1.25/lb of GAC delivered

= 284,000 KG/yr x 2.2 lb/KG x $1.25/lb

= <u>$781,000/yr.</u>

Notes: The 284,000 KG/yr carbon usage is based on the WHC Engineering Report and uses the average expected organic concentration rather than the worse case concentrations. The estimates that generated the 284,000 KG/yr carbon usage are based on isotherm data on single components rather than tests on the actual mixed waste.

3. Storage, Container, & Labor @ $326/ft^3

= $326/ft^3 x 284,000 KG/yr x 2.2 lb/KG x 1 ft^3/29 lbs

= <u>$7,000,000/yr</u>

Notes: Cost for storage and containers were provided by WHC based on assessed costs. Labor costs were estimated based on filling and handling of radioactive material into 55 gallon drums.

GAC = 28-30 lbs/ft^3 bulk density.

III. Combined System

A. Capital = UV/OX was cut in half to reflect decrease in oxidation from 99.9% to 95% ie ln 1000 to ln 20.

GAC capital stayed the same based on IIA notes.

= <u>$1,200,000</u>

B. Operating

1. Power = UV/OX = 1/2
= GAC is negligible

= <u>$72,000/yr.</u>

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2. Chemical = UV/OX is left the same as the H_2O_2 dose of 200 mg/l is still required for optimum oxidation rate.

= GAC usage is cut to 1/4 based on the optimistic assumption that lower concentrations will give lower usage rates. This may not be true but this optimistic case was chosen to evaluate the best possible condition.

= $295,000

3. Storage, Container & Labor = UV/OX taken at 1/2 due to less lamps and tubes to dispose of.

= GAC taken at 1/4

= $1,765,000/yr.

Distribution:

B. A. Austin	WHC	B2-35
J. K. Bartz	MACTEC	A4-35
R. C. Bowman	WHC	H6-24
R. C. Brunke	WHC	H6-23
D. C. Bryson	RL	A5-21
R. M. Carosino	RL	A4-52
C. E. Clark	RL	A5-15
A. J. DiLiberto	WHC	R3-46
D. L. Duncan	EPA	HW-106
J. L. Fields	WHC	H6-24
D. L. Flyckt	WHC	H6-23
M. Jaraysi	Ecology	
B. King	Ecology	
P. J. Mackey	WHC	B3-15
G. R. Mezger	RL	A5-18
J. J. Noble	WHC	L4-94
S. M. Price	WHC	H6-23
H. T. Tilden II	PNL	P7-68

ADMINISTRATIVE RECORD: 200 Area Treatment Facility (ETF, aka PROJECT C-018H), TSD T-2-8 [Care of EPIC, WHC (H6-08)].

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