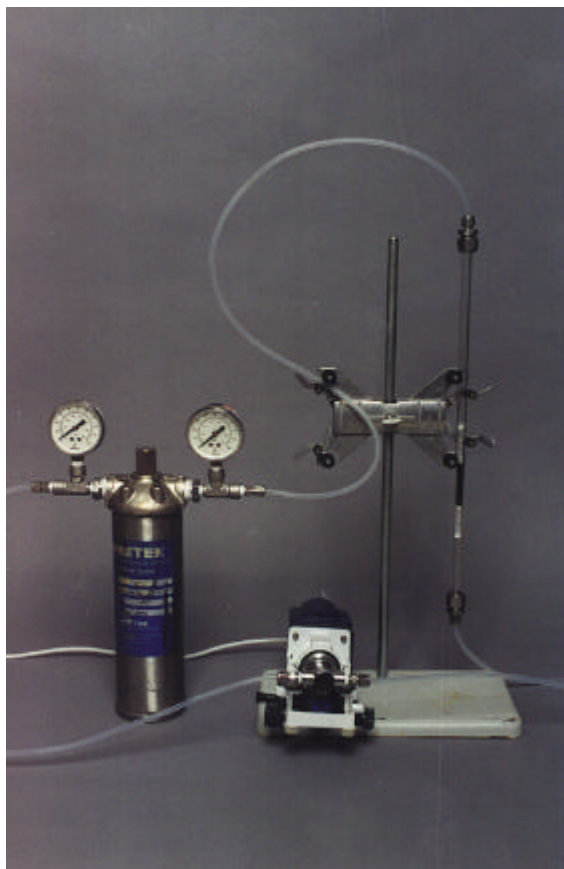

Final Report

ICR Treatment Study Summary Report

Evaluation of GAC Adsorption Technology Using the Rapid Small Scale Column Test for Compliance with the Information Collection Rule

Conducted during the period of 25 February, 1998 to 4 January, 1999



Submitted: July 9, 1999

Submitted by:

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Cypress Street Water Treatment Plant,
ICR # 658

Attachments:

1 CD-ROM containing the *Data Collection
Spreadsheets* and *Treatment Study Summary
Report Spreadsheets*

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1. Conclusions and Recommendations

Finished water quality data collected for the purposes of the ICR (Information Collection Rule) and submitted by the Cypress Street Water Treatment Plant (WTP) indicate that the WTP was within compliance with the Stage 1 MCLs (maximum contaminant levels) for total trihalomethanes (TTHMs, or THM4) and haloacetic acids (HAA5). Annual average concentrations at distribution system monitoring points were 36.6 µg/L for THM4 and 17.6 µg/L for HAA5, compared to Stage 1 MCLs of 80 µg/L and 60 µg/L, respectively. The proposed Stage 2 MCLs for THM4 and HAA5 are 40 µg/L and 30 µg/L, respectively. The average annual concentrations of these compounds in the Cypress Street distribution system also met the proposed Stage 2 MCLs, although the reported maximum value for THM4 (48.8 µg/L) exceeded the proposed Stage 2 level.

The results of this treatment study indicate that compliance with both the Stage 1 MCLs and the more stringent proposed Stage 2 MCLs could be achieved with a granular activated carbon (GAC) adsorption system at the WTP. Implementing GAC adsorption could also provide other water quality benefits, including: (a) removal of trace organics that might be present in the source water; (b) control of tastes and odors; and (c) removal of color, if any; and (d) allowing the use of chlorine for disinfection rather than chloramines. However, installing and operating a GAC adsorption process would be quite expensive and could require an additional operator.

The treatment data show that THM precursors would be more difficult to control than HAA precursors, and that THMs would control carbon usage rates. Simulated distribution system (SDS)-HAA5 concentrations in the influent water were less than the proposed Stage 2 MCLs in three out of four quarters (and just barely above the MCL in the other quarter), and therefore no treatment was required for removal of HAA precursors. The data also show that GAC adsorbers sized to provide a 20-minute empty bed contact time (EBCT) would provide more efficient use of carbon than 10-minute EBCT adsorbers. Carbon usage, based on the simulated distribution system (SDS) test results, could be expected to be substantially higher in the second quarter (around June). Peak carbon requirements were estimated to be about 1,490 to 2,500 lbs/MG, whereas the carbon requirements in other quarters may be 40 to 60% of those rates. These carbon usage rates are quite high compared to rates experienced at many other water treatment plants employing GAC adsorption.

While GAC adsorption is an effective technology for controlling disinfection by-products (DBPs) in finished drinking water, there are other alternatives (e.g., use of ozone as primary disinfectant, use of chloramines for post-disinfection, membrane treatment). For example, membrane treatment may be a more attractive option than GAC because it could be used for both DBP control and hardness reduction. It is recommended that the public water supplier develop WTP-specific water quality goals, and then consider all practical options for achieving those goals before choosing a treatment strategy.

2. Background Information

2.1 Treatment Plant Description

The City of Wichita Falls, Texas, Cypress Street Water Treatment Plant has a capacity of 32 MGD and serves approximately 60,000 people. Figure 2-1 is a schematic of the water treatment plant (WTP). The WTP has two parallel treatment trains, referred to here as the Clarifier and the Conventional process trains, the former representing the treatment train employing a solids contact clarifier and the latter representing the treatment train using conventional rapid mix, flocculation, and sedimentation. Typically, the Clarifier train is operated alone until the water demand exceeds 16 MGD, and then the Conventional train is brought online with a 50-50 split between the two process trains. Treatment in each process train consists of coagulation/flocculation, chemical softening, recarbonation, media filtration, and pre- and post-disinfection. Treatment plant design data are summarized in Table 2-1.

The main treatment challenges at the WTP are:

- Turbidity and particulates
- Hardness
- Disinfection
- Disinfection byproducts

Turbidity and particles are removed by chemical coagulation using ferric sulfate and polymer and hardness is reduced by lime softening. Disinfection for the removal of potential pathogens is performed at the beginning and end of the treatment trains. Unfortunately, disinfection can and does produce unwanted byproducts. Disinfection byproduct (DBP) formation is held in check at the plant by using chlorine dioxide and chloramines for pre-disinfection and by removing precursor material before post-disinfection.

2.2 Source/Finished Water Quality

Tables 2-2 and 2-3 summarize source and finished water quality characteristics for the Cypress Steet Plant for the period of January through December 1998. The finished water data show that distribution system (DS)-THM4 and DS-HAA5 concentrations are considerably lower than the Stage 1 MCLs (80 µg/L and 60 µg/L, respectively) and slightly lower than the proposed Stage 2 MCLs (40 µg/L and 30 µg/L, respectively).

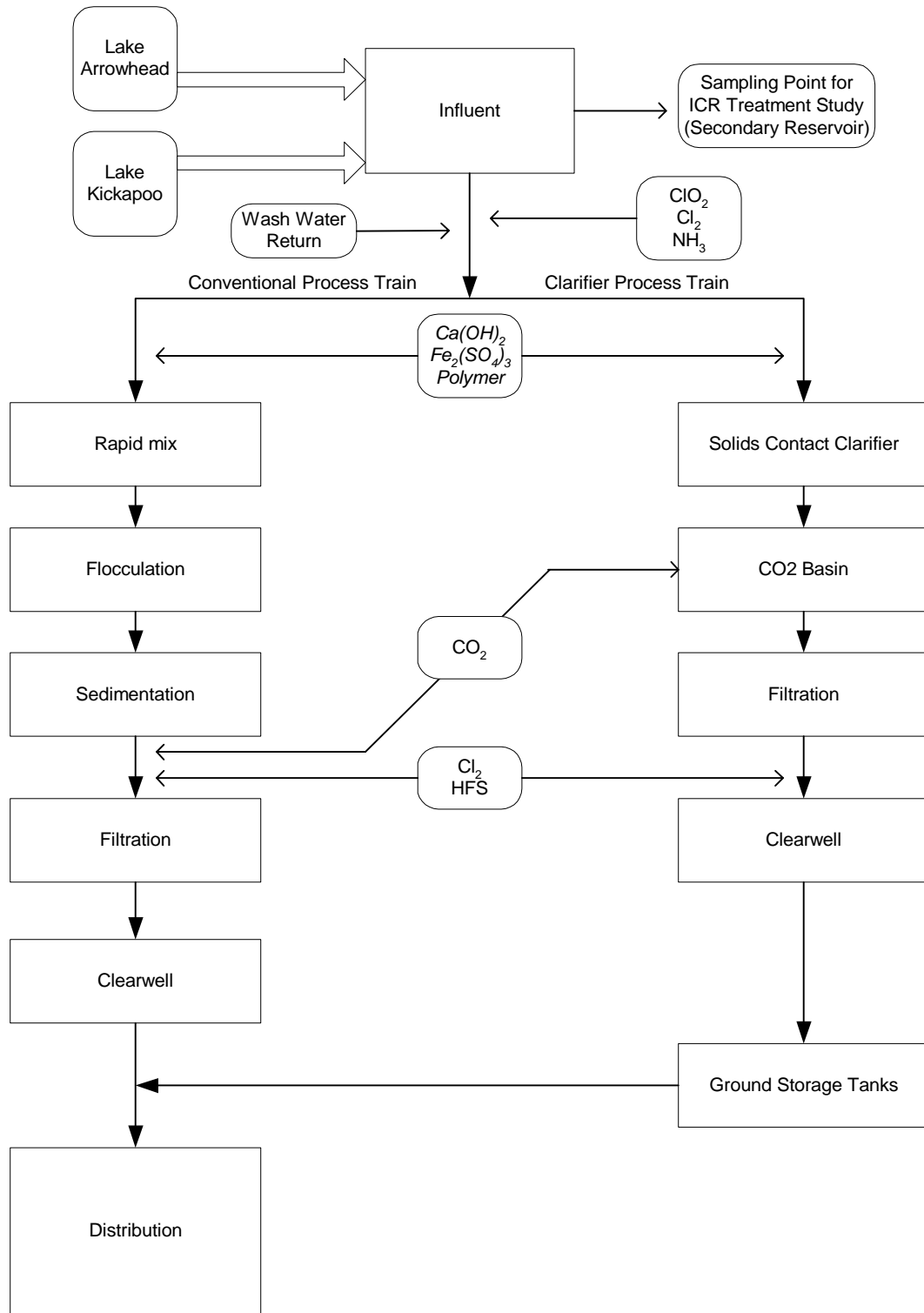


FIGURE 2-1
Cypress Street Water Treatment Plant Schematic

TABLE 2-1
Water Treatment Plant Design Data

Combined Flow									
Unit Process			Process Description						
Disinfection			Chemical type	ClO ₂					
			Dosage (mg/L as Cl ₂)	1.0					
			Chemical type	Cl ₂					
			Dosage (mg/L as Cl ₂)	4.5					
			Chemical type	NH ₃					
			Dosage (mg/L as NH ₃)	1.5					
Coagulation Chemical Addition			Coagulant	Fe ₂ (SO ₄) ₃					
			Dosage (mg/L as Fe)	10-20					
			Polymer	Cationic, PRC-320					
			Dosage (mg/L)	0-10					
Split Flow									
Conventional Process Train			Clarifier Process Train						
Unit Process	Process Description		Unit Process	Process Description					
Rapid Mix	Type of mixer	Hydraulic	Coagulation, Softening, and Sedimentation	Clarifier type	Solids contact				
	Baffling type	None		Surface area (ft ²)	8,602				
	Liquid volume (gal)	4,345		Baffling type	Poor				
	Chemical type	Ca(OH) ₂		Liquid volume (gal)	1,435,807				
	Dosage (mg/L)	90-100		Chemical type	Ca(OH) ₂				
Flocculation	Type of mixer Baffling type	Mechanical Avg: in/out/intermed 384,850	Recarbonation	Surface area (ft ²) Baffling type Liquid volume (gal) Chemical type Dosage (mg/L)	90-100				
					Liquid vol. (gal)	88			
						Stage No. Stage mean velocity gradient (sec ⁻¹) Stage liquid vol (gal)	Average		
	Stage No. Stage mean velocity gradient (sec ⁻¹) Stage liquid vol (gal)	6,580							
		24.0 192,425			CO ₂				
					24.0 192,425	25-30			
	Sedimentation					Surface area (ft ²) Baffling type Liquid volume (gal)	40,000 Avg 4,640,700	Filtration	Surface area (ft ²) Liquid volume (gal) Total media depth (in) Min water depth to top of media (ft) Depth from top of media to top of backwash trough (ft)
		80,784							
		33							
		16.8							
					5.1				

Split Flow (cont'd)					
Conventional Process Train			Clarifier Process Train		
Unit Process	Process Description		Unit Process	Process Description	
Disinfection (plus recarbonation and fluoridation)	Chemical type Dosage (mg/L as Cl ₂) Chemical type Dosage (mg/L) Chemical type Dosage (mg/L as F)	Cl ₂ 1.5 CO ₂ 25-30 Hydrofluorosilic acid 0.7	Disinfection (plus fluoridation)	Chemical type Dosage (mg/L as Cl ₂) Chemical type Dosage (mg/L as F)	Cl ₂ 1.5 Hydrofluorosilic acid 0.7
Filtration	Surface area (ft ²) Liquid volume (gal) Total media depth (in) Min water depth to top of media (in) Depth from top of media to top of backwash trough (in)	6,061 164,344 34 6.8 3.8	Clear Well	Surface area (ft ²) Baffling type Liquid volume (gal) Covered contactor	960 Unbaffled 165,768 Yes
Clear Well	Surface area (ft ²) Baffling type Liquid volume (gal) Covered contactor	1,315 Poor 115,000 Yes	Ground Storage Tanks	Liquid volume (gal)	8,000,000

TABLE 2-2

Source Water Quality

Water Quality Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature	°C	20.5	8.11	36.6	9.43
pH	pH units	8.3	0.1	8.5	8.1
Turbidity	ntu	33.4	10.6	54.7	24.2
Alkalinity	mg/L as CaCO ₃	147	7.6	159	136
Calcium Hardness	mg/L as CaCO ₃	105	9.48	121	93
Total Hardness	mg/L as CaCO ₃	154	9.60	168	144
TOC	mg/L	5.02	0.803	5.89	3.32
UV254	cm ⁻¹	0.148	0.026	0.200	0.120
SUVA	L/(mg-m)	2.97	0.80	4.20	2.04
Bromide	µg/L	0.45	0.09	0.57	0.28

SUVA = specific ultraviolet absorbance = UV254*100/TOC

TABLE 2-3

Finished Water Quality

Water Quality Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature	°C	19.3	7.47	29.2	8.82
pH	pH units	8.74	0.2	8.96	8.57
Turbidity	ntu	0.04	0.0	0.05	0.03
TOC	mg/L	3.51	0.47	4.23	2.57
UV254	cm ⁻¹	0.059	0.007	0.068	0.047
SUVA	L/(mg-m)	1.74	0.226	2.12	1.35
DS - THM4	µg/L	36.6	14.2	48.8	17.8
DS - HAA5	µg/L	17.6	2.09	19.7	14.7

DS = distribution system, the DS data are averaged over four sampling locations

SUVA = specific ultraviolet absorbance = UV254*100/TOC

3. Materials and Methods

3.1 Pretreatment

The water sample for treatability testing was collected at the secondary reservoir (a reservoir tank before the WTP headworks) and pretreated in the lab to avoid the presence of chlorine compounds in the test water. Pretreatment was designed to simulate chemical treatment and TOC removal at the WTP. Pretreatment prior to advanced treatment process testing consisted of coagulation/softening, flocculation, sedimentation, recarbonation, and filtration. Coagulation/softening, flocculation, and sedimentation were performed in a single batch (each quarter) using a large (200-gal) cone-bottom polyethylene tank and a mechanical mixer. The doses of ferric sulfate, lime, and cationic polymer were matched to those used at the WTP on the date each quarterly sample was collected. Figure 3-1 is a schematic of the first three pretreatment processes, and Table 3-1 gives pretreatment design information. Following sedimentation, the clarified water was decanted, recarbonated to reduce pH by bubbling CO₂ through the water, and transferred to the feed tanks for advanced treatment process testing. During advanced treatment process testing, this feed water was filtered through an in-line Teflon cartridge filter (0.1- μ m pore size) installed upstream from the bench-scale carbon columns.

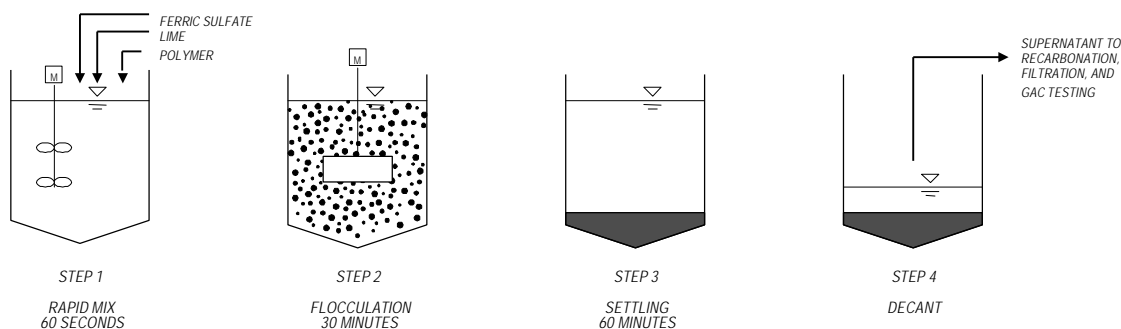


Figure 3-1. Schematic of bench-scale pretreatment processes

3.2 Advanced Treatment Process

Granular activated carbon (GAC) treatment was simulated using rapid small-scale column tests (RSSCTs). These tests were performed in accordance with the *ICR Manual for Bench- and Pilot-Scale Treatment Studies* (EPA, 1996a). Figure 3-2 is a schematic of the RSSCT apparatus. The

process equipment included a feed tank, feed pump, glass carbon column, glass effluent sampling vessel and plastic effluent tank, Teflon tubing, and stainless steel fittings. All surfaces in contact with the test water were made of inert materials such as Teflon, glass, and stainless steel. Table 3-2 lists RSSCT design data. TOC concentrations measured immediately after pretreatment (i.e., RSSCT Influent TOC in Table 3-2) were used in RSSCT design calculations.

Calgon F-300 carbon was prepared for use in the RSSCTs as follows. A representative sample of GAC was taken from the carbon stock and ground so that the entire amount passed through a 60-mesh sieve (the upper sieve mesh size). The ground carbon passing the 60-mesh sieve but retained on the 80-mesh sieve (the lower sieve mesh size) was reserved for RSSCT testing. After sieving, the ground carbon was washed with organic-free water using the step-wise decanting procedure described in the guidance manual (EPA, 1996a). For carbon:wash-vessel volume ratios of 0.1 or less, about 10 wash-vessel volumes of organic-free water were used for carbon washing. After washing, the ground carbon was dried overnight to a constant weight in a drying oven at 80-90°C. The washed and dried carbon was then transferred to a clean bottle and stored in a desiccator until used. The density of the ground carbon was determined by precisely weighing 2 g of dry carbon and measuring its volume in a 5-mL graduated cylinder.

The carbon columns were prepared for testing as follows:

- Weighing out the pre-determined amount of dry ground carbon required for the column test.
- Pre-wetting the carbon by placing it in an Erlenmeyer flask, covering it with organic-free water, and allowing it to sit overnight.
- De-aerating the carbon/water mixture by applying a vacuum to the flask for at least 15 minutes.
- Filling the column to about 25% of the planned GAC bed depth with de-aerated, organic-free water and ensure that the carbon remains entirely submerged throughout the loading process.
- Transferring the carbon/water slurry to the column, while gently tapping the column to promote packing of the GAC particles.
- Checking RSSCT system integrity for leaks, air pockets, immediate head loss build-up, etc., by operating the system with organic-free water for about 10 minutes.
- Purging the feed system and columns of air and organic-free water with the feed solution (test water).

Test start-up and operation involved filling the feed tank with test water, connecting the feed system, initiating feed delivery and setting the feed flow rate, maintaining the system during operation, and collecting samples at appropriate intervals for analysis. Flow rates were checked daily and maintained within 5% of the target value. Pressure was also checked daily to monitor head loss. An RSSCT was operated until the effluent TOC concentration was at least 70% of the average influent TOC concentration on two consecutive sample times.

3.3 Experimental Design

RSSCT testing was performed quarterly as shown in Table 3-3. The purpose of this experimental design was to evaluate seasonal variability and carbon treatment at two empty

bed contact times (EBCT = 10 and 20 minutes). The two EBCT tests were run concurrently using a common feed tank.

3.4 Sampling and Analysis

Table 3-4 presents the RSSCT sampling plan. Table 3-5 records the analytical methods used during the treatment study, along with the minimum reporting levels. All analyses associated with this treatment study were performed on-site by CH2M HILL's Applied Science Laboratory in Corvallis, Oregon. Required laboratory information is given below:

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Applied Science Laboratory
2300 NW Walnut Blvd
Corvallis, Oregon 97330
ICR Lab ID No.: ICROR001

Lab contact: Kathy McKinley
Phone: 541/752-4271
Fax: 541/752-0276

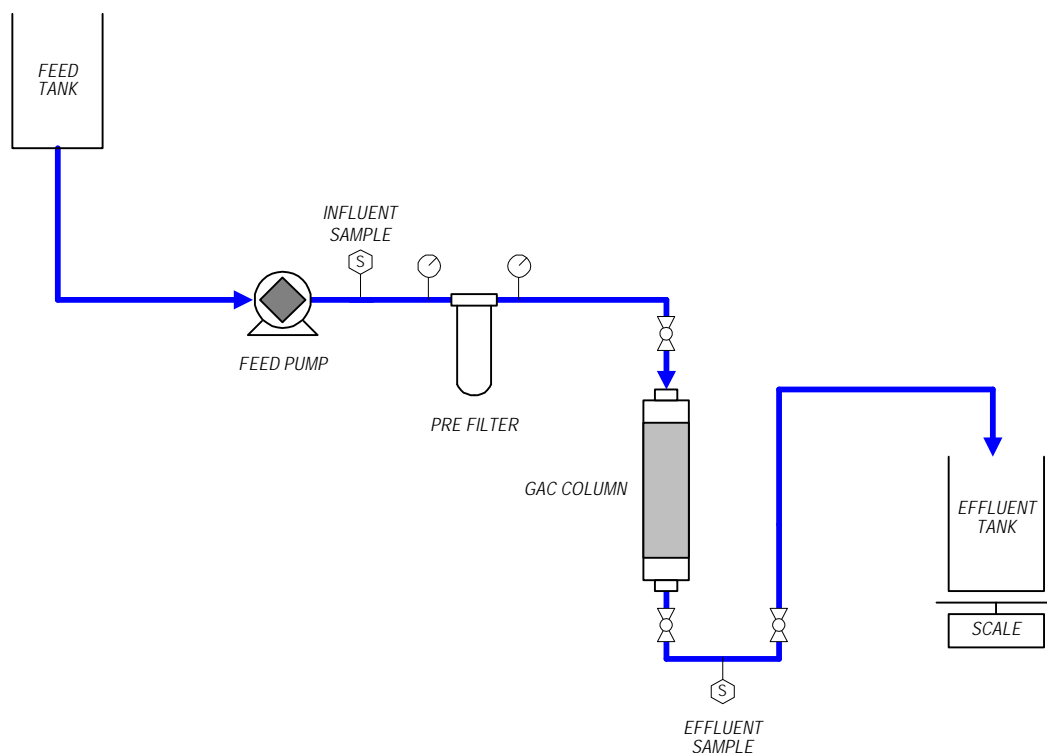


Figure 3-2. Schematic of RSSCT apparatus

TABLE 3-1
Pretreatment Design Data

Unit Process	Process Description			
	1 st Quarter (Feb-98)	2 nd Quarter (Jun-98)	3 rd Quarter (Aug-98)	4 th Quarter (Nov-98)
Coagulation				
Ferric Sulfate Dose (mg/L)	12	12	6	19
Lime Dose (mg/L)	100	100	100	100
Polymer Dose (mg/L) ^a	0.1	0.1	0.1	0.1
pH after chemical addition	NR	10.8	10.8	10.3
Rapid Mix Time (min)	1.0	1.0	1.0	1.0
Flocculation				
Flocculation Time (min)	30	30	30	30
Sedimentation				
Settling Time (min)	45	60	60	60
Recarbonation				
pH after CO ₂ addition	8.9	8.3	8.4	8.5
Filtration				
Teflon cartridge filter pore size (µm)	0.1	0.1	0.1	0.1

NR = Not Reported

^a Allied Colloids LT22S

TABLE 3-2
RSSCT Design Data

Input Design Parameters	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
RSSCT influent TOC (mg/L)	3.8	4.8	4.9	4.87
Inner diameter of the RSSCT column, D_{SC} (mm)	8.0	8.0	8.0	8.0
Minimum RSSCT Reynolds number, $Re_{SC, min}$	0.5	0.5	0.5	0.5
Full-scale operating temperature($^{\circ}$ C)	8.0	26.0	27.0	16.0
Full-scale bed porosity, e_{LC}	0.42	0.42	0.42	0.42
Measured RSSCT dry bed density, ρ_{SC} (g/cm ³)	0.56	0.46	0.443	0.443
RSSCT GAC mesh size, upper (US standard mesh)	60	60	60	60
RSSCT GAC mesh size, lower (US standard mesh)	80	80	80	80
Estimated Run Length				
Bed volumes to 50% TOC breakthrough, BV_{50}	3826	2824	2749	2771
Estimated run length, BV_T (= 2 x BV_{50})	7652	5648	5498	5542
BV_T + 30% safety factor, $BV_{T+30\%}$ (= 2.6 x BV_{50})	9948	7342	7148	7205
General RSSCT Design Parameters				
Kinematic viscosity at T° C, ν_{LC} (m ² /s)	1.39E-06	1.39E-06	8.69E-07	1.13E-06
RSSCT carbon particle diameter, d_{SC} (mm)	0.215	0.215	0.215	0.215
Scaling factor, SF	6.88	6.88	6.88	6.88
RSSCT hydraulic loading rate, v_{SC} (m/hr)	4.90	4.90	3.05	3.99
RSSCT flow rate, Q_{SC} (mL/min)	4.11	4.11	2.56	3.34
Estimated total influent volume required, V_{SC}^T (L)	178	131	80	105
10-Minute EBCT Run				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	10	10	10	10
Estimated full-scale run time, t_{LC}^T (days)	69	51	50	50
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.45	1.45	1.45	1.45
Estimated RSSCT run time, t_{SC}^T (days)	10.04	7.41	7.21	7.27
RSSCT bed length, l_{SC} (cm)	11.9	11.9	7.4	9.7
Estimated volume required for 10-minute EBCT, V_{SC} (L)	59	44	27	35
Mass GAC required, m_{SC} (g)	3.34	2.74	1.65	2.15
20-Minute EBCT Run				
Full-scale empty bed contact time, $EBCT_{LC}$ (min)	20	20	20	20
Estimated full-scale run time, t_{LC}^T (days)	138	102	99	100
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.91	2.91	2.91	2.91
Estimated RSSCT run time, t_{SC}^T (days)	20.07	14.81	14.42	14.54
RSSCT bed length, l_{SC} (cm)	23.7	23.7	14.8	19.3
Estimated volume required for 20-minute EBCT, V_{SC} (L)	119	88	53	70

TABLE 3-3
RSSCT Experimental Design

Season	Pretreatment	EBCT [min]
1 st Quarter (February)	Softening	10 & 20
2 nd Quarter (June)	Softening	10 & 20
3 rd Quarter (August)	Softening	10 & 20
4 th Quarter (November)	Softening	10 & 20

TABLE 3-4
RSSCT Sample Requirements

Parameter	Sample Location	No. of Samples/Test
pH	Influent	2
	10-min EBCT Effluent	15 ^b
	20-min EBCT Effluent	15 ^b
NH3-N	Influent	2
Calcium Hardness	Influent	2
Total Hardness	Influent	2
Bromide	Influent	2
Alkalinity	Influent	2
Temperature	Influent	3
Turbidity	Influent	3
	10-min EBCT Effluent	15 ^b
	20-min EBCT Effluent	15 ^b
TOC	Influent	3
	10-min EBCT Effluent	15 ^b
	20-min EBCT Effluent	15 ^b
UV254	Influent	3
	10-min EBCT Effluent	15 ^b
	20-min EBCT Effluent	15 ^b
SDS Test ^a	Influent	3
	10-min EBCT Effluent	15 ^b
	20-min EBCT Effluent	15 ^b

^a SDS Test samples analyzed for THMs, HAAs, TOX, and Free Chlorine Residual

^b Includes 3 duplicates

TABLE 3-5
RSSCT Analytical Methods and MRLs

Parameter	Analytical Method	Minimum Reporting Level
pH	SM 4500-H ⁺	Not Applicable
Ammonia	SM 4500-NH ₃ D	0.10 mg/L as NH ₃ -N
Calcium Hardness	EPA 200.7	5 mg/L as CaCO ₃
Total Hardness	SM 2340 D	5 mg/L as CaCO ₃
Bromide	EPA 300.0	10 µg/L
Alkalinity	SM 2320 B	5 mg/L as CaCO ₃
Temperature	Thermometer	Not Applicable
Turbidity	SM 2130 B	0.05 ntu
TOC	SM 5310 D	0.50 mg/L
TOX	SM 5320 B	25 µg/L as Cl
UV254	SM 5910	0.009 cm ⁻¹
THMs: CHCl ₃ , BDCM, DBCM, CHBr ₃	EPA 551.1	0.5 µg/L for each analyte
HAAs: BCAA, DBAA, DCAA, MBAA, MCAA, TCAA	SM 6251 B	1.0 µg/L for each analyte, except 2.0 µg/L for MCAA
Free Chlorine Residual	SM 4500-Cl G	0.05 mg/L

4. Results and Discussion

According to the *ICR Treatment Studies Data Collection Spreadsheets User's Guide* (EPA, 1997), the purpose of this section is **not** to report the detailed data included in the *Data Collection Spreadsheets* (submitted along with this *Treatment Study Summary Report*), but rather to provide information that is critical to the interpretation of the results reported in the spreadsheets and to succinctly report the key findings.

4.1 Problems Encountered

RSSCT operation was generally problem-free. The test systems were operated continuously each quarter without any shutdown periods.

4.2 Influent Water Quality

Table 4-1 presents the average water quality characteristics of the pretreated water (RSSCT influent before filtration). For a given season, influent water characteristics were identical for the 10- and 20-minute EBCT RSSCT systems because they used a common feed tank. The simulated distribution system (SDS)-TOX, SDS-THM, and SDS-HAA concentrations were highest in the 2nd Quarter of testing and higher in the 3rd, and 4th Quarters than in the 1st Quarter. Elevated TOC, SDS-THM, and SDS-HAA concentrations are important because higher levels of these parameters result in faster exhaustion of GAC. Turbidity was relatively high in the 2nd Quarter and especially the 4th Quarter. Turbidity normally does not affect the rate of GAC exhaustion. Elevated turbidity increases the rate of head loss build-up, but head loss was not a problem during RSSCT operation.

Table 4-2 shows average simulated distribution system (SDS) test conditions for RSSCT influent water samples. The target free chlorine residual was 0.5 to 1.0 mg/L after the contact time chosen to match that reported by the WTP for the sampling date. The EPA allows some latitude in meeting the target conditions and sets a goal of ± 0.4 mg/L. If the target residual is taken as 0.75 mg/L, the EPA allows a range of 0.35 to 1.15 mg/L. In 8 out of 12 cases (67%) this goal was met. Three 2nd Quarter samples were above this range and one 3rd Quarter sample was below this range. EPA does not consider a residual outside the target range to constitute a failure of the SDS test.

The seasonal variation in THM and HAA formation in the feed water SDS tests may have been due to the different temperatures used in the SDS tests (to simulate seasonal temperature changes) and the slightly elevated TOC levels in the latter three quarters. The Stage 1 MCLs for THM4 and HAA5 are 80 and 60 $\mu\text{g/L}$, respectively. The influent water SDS-THM4 concentrations exceeded these regulatory levels in the 2nd, 3rd, and 4th Quarters, whereas the influent SDS-HAA5 concentrations were below the Stage 1 MCL in all four quarters.

4.3 RSSCT Results

RSSCT breakthrough curves for TOC, THM4, and HAA5 are presented in Figures 4-1 through 4-4, for the four quarters of testing. The data are presented in two forms. On the left, measured effluent concentrations are plotted versus operation time of a full-scale carbon adsorber (the scaling factor determined as the ratio of the full-scale-to-RSSCT carbon particle diameter [d_{Lc}/d_{sc}] was 6.88). On the right, normalized effluent concentrations (effluent concentration/influent concentration) are plotted as a function of the number of bed volumes treated ($BV = \text{operation time}/EBCT$). The latter data display provides a more practical comparison of the two different EBCTs. For a given flow, a 20-min EBCT adsorber would need to be twice as large as a 10-min EBCT adsorber, so operation times until breakthrough cannot be compared directly to evaluate carbon regeneration costs. In general, the breakthrough curves exhibit a fairly typical pattern of a relatively rapid breakthrough phase followed by a relatively slow breakthrough phase.

GAC treatment is typically evaluated in terms of treatment objectives. For THMs and HAAs, the proposed Stage 2 regulatory limits (MCLs) of 40 $\mu\text{g/L}$ for THM4 and 30 $\mu\text{g/L}$ for HAA5 are good treatment objectives and will be used as breakthrough criteria. There is no regulatory limit for TOC so a breakthrough criterion of 30% removal will be used in this discussion. Table 4-3 summarizes the breakthrough thresholds for TOC, SDS-THM, and SDS-HAA5 in terms of operation time and throughput volume from the treatment study results.

The data show that THM precursors were consistently more difficult to control than HAA precursors. SDS-HAA5 concentrations in the RSSCT influent were less than the breakthrough criterion in all but the 2nd Quarter, so time to HAA breakthrough was virtually infinite. In all four quarters, THM precursors broke through the carbon in a relatively short period of time, and, therefore, SDS-THM4 would dictate regeneration requirements (Figure 4-5). SDS-THM4 breakthrough was particularly rapid in the 2nd Quarter.

The data also indicate that there is some benefit to using a 20-min EBCT GAC adsorber over a 10-min EBCT adsorber. The 20-min EBCT system treated from 1.5 to 1.9 times more bed volumes before SDS-THM4 breakthrough than the 10-min system, in all four quarters (Figure 4-6). Restated, the 20-min EBCT system provided more efficient use of the carbon.

Table 4-4 summarizes average SDS test conditions for GAC effluent water samples. The target free chlorine residual was 0.5 to 1.0 mg/L after the contact time chosen to match that reported by the WTP for the sampling date. The EPA allows some latitude in meeting the target conditions and sets a goal of $\pm 0.4 \text{ mg/L}$. If the target residual is taken as 0.75 mg/L , the EPA allows a range of 0.35 to 1.15 mg/L . In 105 out of 126 cases (83%) this goal was met. EPA does not consider a residual outside the target range to constitute a failure of the SDS test.

4.4 Impact of Seasonal Variability

The GAC service life until breakthrough varied considerably over the four quarters of testing. Table 4-1 reveals that SDS-THM4 and SDS-HAA5 concentrations in the RSSCT influent peaked

in the 2nd Quarter (June), and that influent TOC was relatively high in the 2nd, 3rd, and 4th Quarters. Variations in these parameters are shown in Figure 4-7.

Figures 4-5 and 4-6 illustrate the seasonal variability in the volume of water that could be treated before breakthrough of THM precursors occurred, indicating exhaustion of the GAC. Table 4-5 summarizes estimated carbon usage rates for each quarter based on the 20-min EBCT RSSCT results. These data indicate that carbon usage would be substantially higher in the 2nd Quarter (June) than in the other quarters. Carbon usage rates and regeneration frequencies can be decreased by staggering regeneration so that there is always some fresher and some older GAC in use. The better water produced by the fresher carbon would be mixed with the poorer water produced by the older carbon to obtain blended water that would meet the treatment objectives. Through experience, regeneration can be timed to maintain a relatively constant blended water quality. Such an approach typically reduces carbon usage rates by 30-40%. For example, it may be possible to reduce the 2nd Quarter carbon requirement from 2,480 to 1,490 lbs/MG. Even so, this would be a markedly high carbon usage rate.

TABLE 4-1
RSSCT Influent Water Quality

Parameter	Units	1st Quarter (Feb-98) Average [CV %]	2nd Quarter (Jun-98) Average [CV %]	3rd Quarter (Aug-98) Average [CV %]	4th Quarter (Nov-98) Average [CV %]
Alkalinity*	mg/L as CaCO ₃	55.0 [40.0]	62.0 [0.00]	74.7 [11.5]	77.8 [0.64]
Total hardness*	mg/L as CaCO ₃	64.2 [22.0]	82.8 [10.4]	90.5 [6.74]	98.6 [2.84]
Calcium hardness*	mg/L as CaCO ₃	26.5 [20.8]	33.6 [9.5]	40.6 [19.0]	45.5 [2.64]
Ammonia*	mg/L as N	BMRL	BMRL	0.1	BMRL
Bromide*	µg/L	369 [8.41]	478 [2.09]	504	541 [0.56]
pH	pH units	9.36 [1.74]	9.44 [4.86]	8.08 [3.47]	8.22 [0.49]
Turbidity	ntu	0.220 [34.3]	0.41 [18.8]	0.24 [27.3]	0.66 [123]
Temperature	°C	21.0 [0.00]	20.0 [0.00]	20.0 [0.00]	20.0 [0.00]
Total organic carbon	mg/L	3.92 [10.3]	4.77 [2.32]	4.49 [8.12]	4.99 [3.71]
UV254	cm ⁻¹	0.067 [0.00]	0.092 [2.75]	0.085 [2.35]	0.084 [1.04]
SUVA	L/(mg*m)	1.72 [9.83]	1.92 [5.04]	1.90 [8.59]	1.67 [3.84]
SDS-Cl ₂ demand	mg/L	1.40 [1.09]	2.40 [7.35]	1.99 [11.6]	1.88 [2.72]
SDS-TOX	µg/L as Cl ⁻	92.4 [1.51]	223 [18.0]	163 [20.0]	155 [7.49]
SDS-THM ₄	µg/L	76.8 [1.19]	125 [3.13]	94.5 [7.79]	94.1 [6.84]
SDS-HAA ₅	µg/L	20.0 [2.42]	36.5 [5.21]	21.6 [11.7]*	19.1 [4.62]
SDS-HAA ₆	µg/L	27.5 [2.31]	49.6 [5.63]	29.1 [13.3]*	25.2 [4.06]

BMRL = Below Minimum Reporting Level

SDS = Simulated distribution system

SUVA = Specific ultraviolet absorbance = UV254*100/TOC

CV = Coefficient of variation = (standard deviation/mean)(100%)

*: For these parameters, values in brackets represent Relative Percent Difference(RPD). Defined as
[(Sample 1 - Sample 2)/Sample Average] x 100%

TABLE 4-2

RSSCT Influent Water SDS Test Conditions

Parameter	1st Quarter (Feb-98)	2nd Quarter (Jun-98)	3rd Quarter (Aug-98)	4th Quarter (Nov-98)
Average pH	8.95	8.31	8.37	8.41
Average temperature [°C]	8.0	25.0	25.0	16.2
Average contact time [hr]	6.97	4.04	1.99	4.42
Chlorine dose [mg/L]	2.00	4.02	2.49	2.89
Free chlorine residual [mg/L]	0.59 - 0.62 Average: 0.60	1.53 - 1.80 Average: 1.62	0.23 - 0.87 Average: 0.50	0.86 - 1.12 Average: 1.01

FIGURE 4-1
1st Quarter Breakthrough Curves

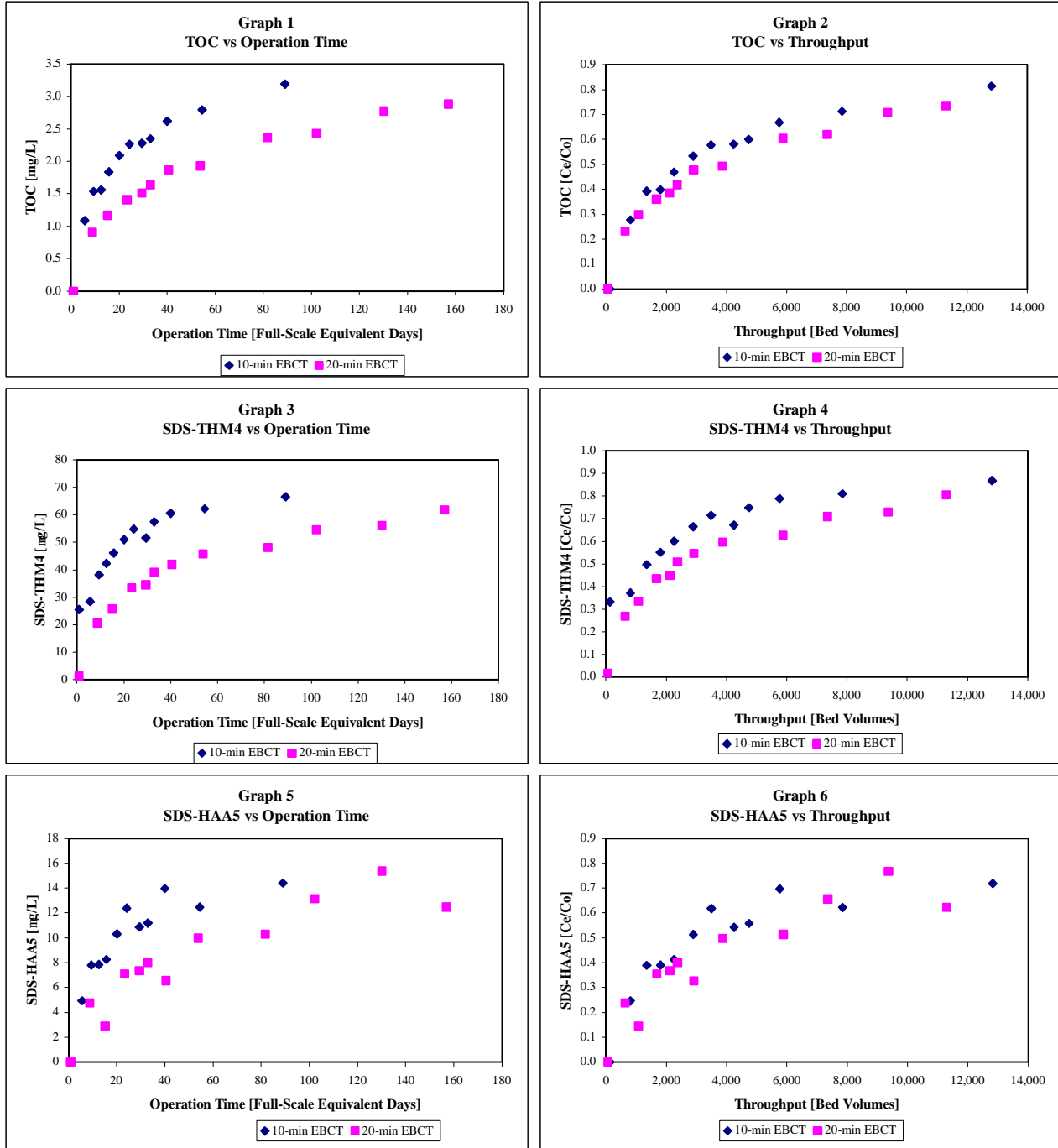


FIGURE 4-2
2nd Quarter Breakthrough Curves

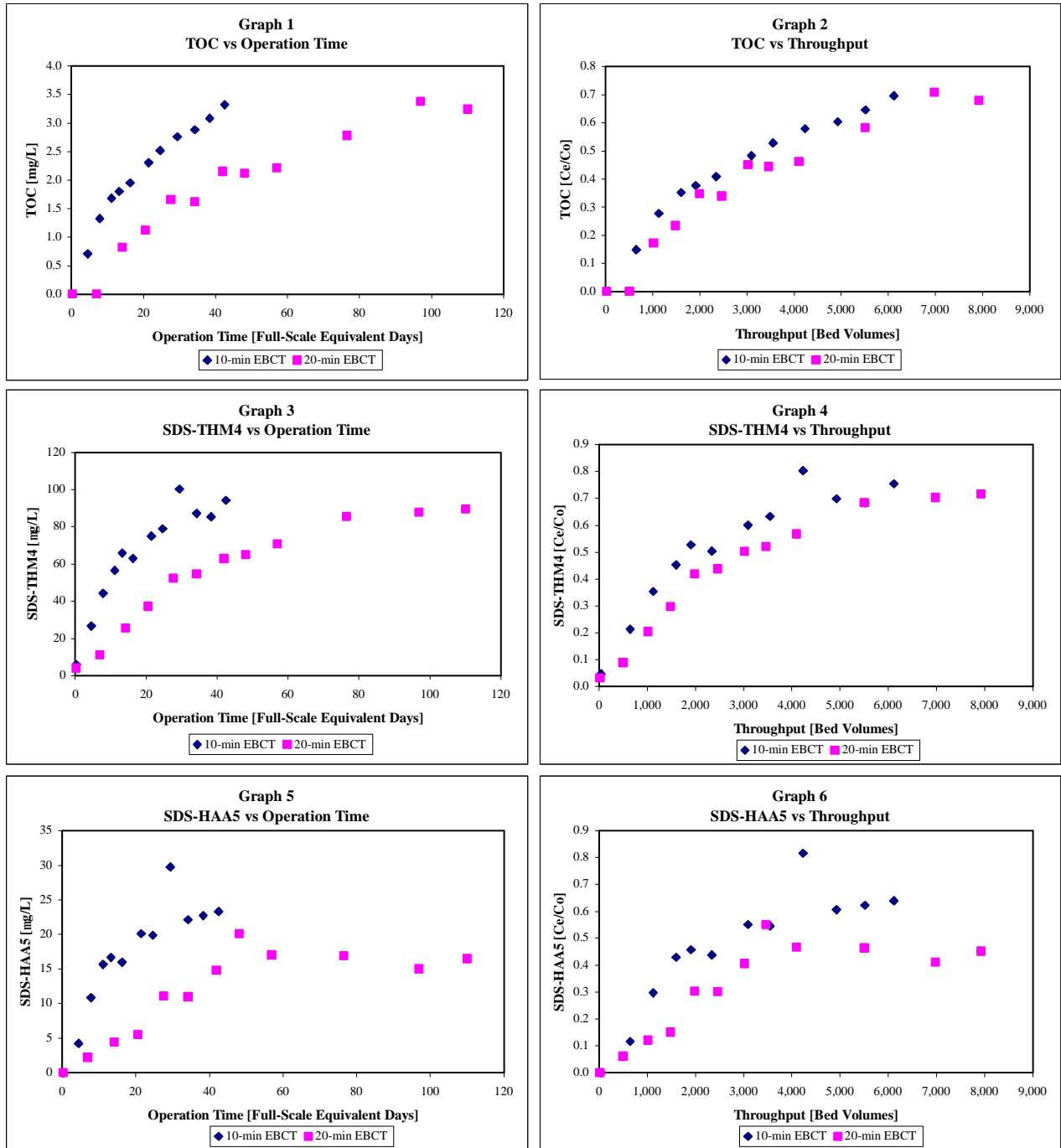


FIGURE 4-3
3rd Quarter Breakthrough Curves

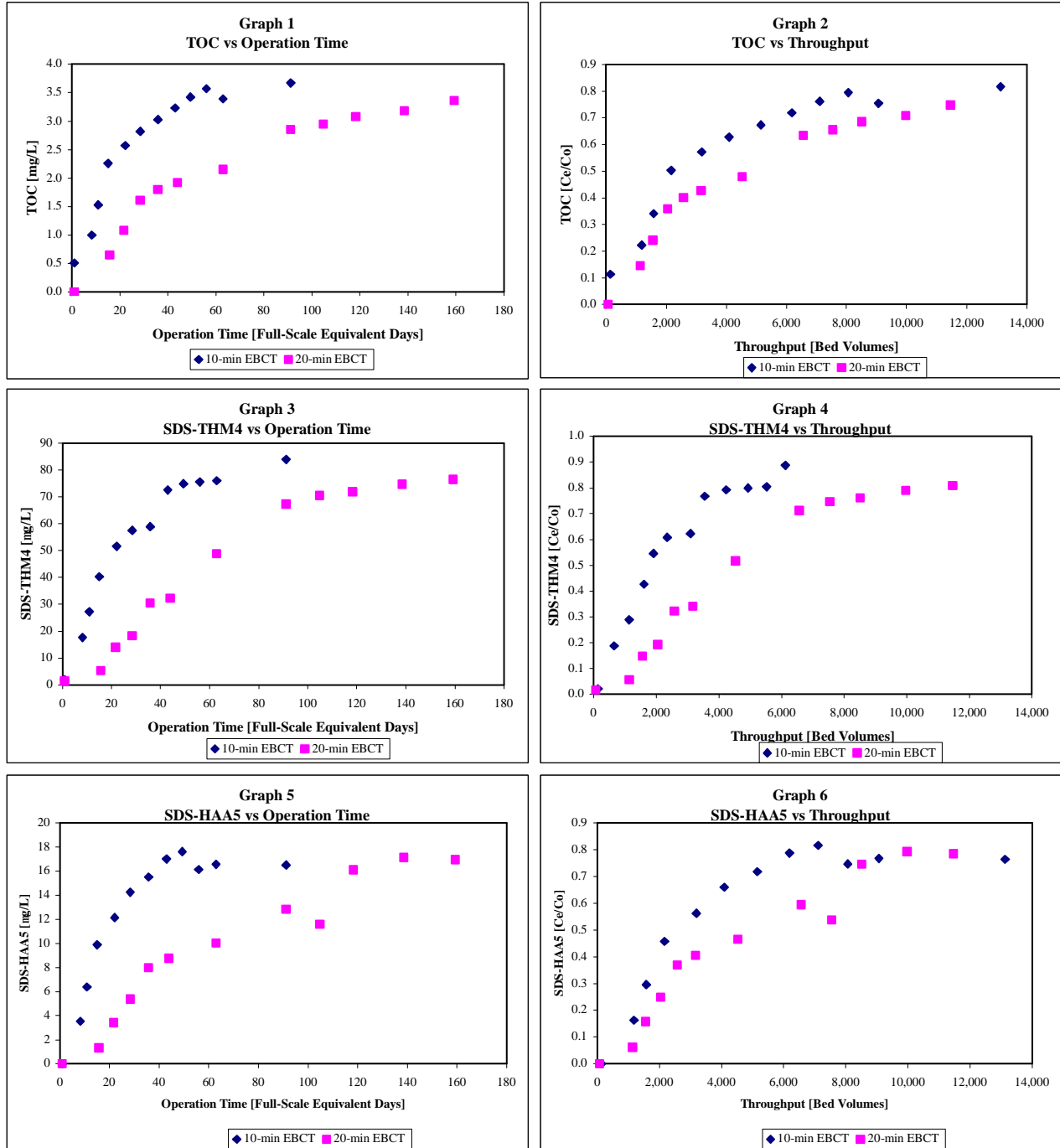


FIGURE 4-4
4th Quarter Breakthrough Curves

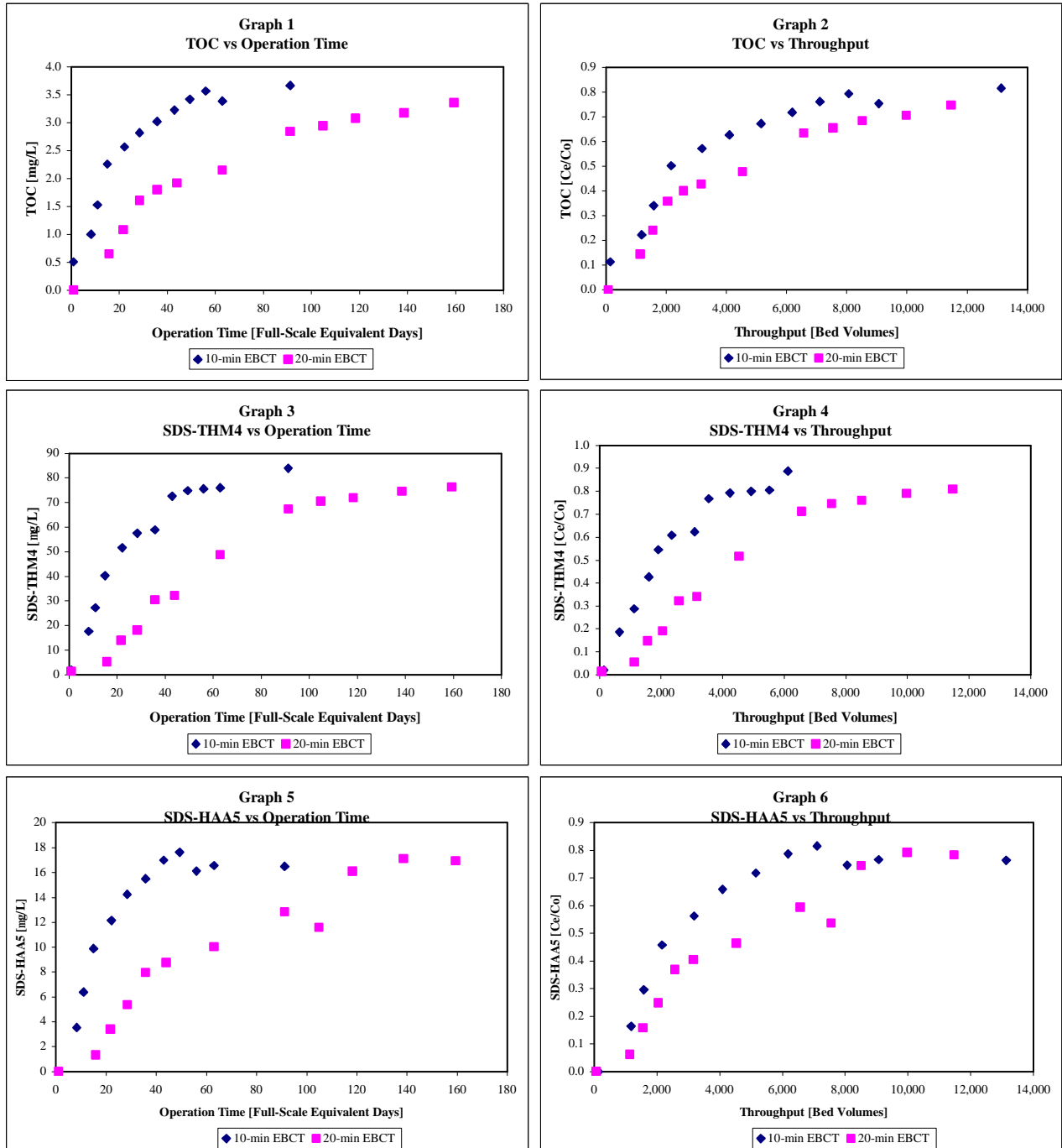


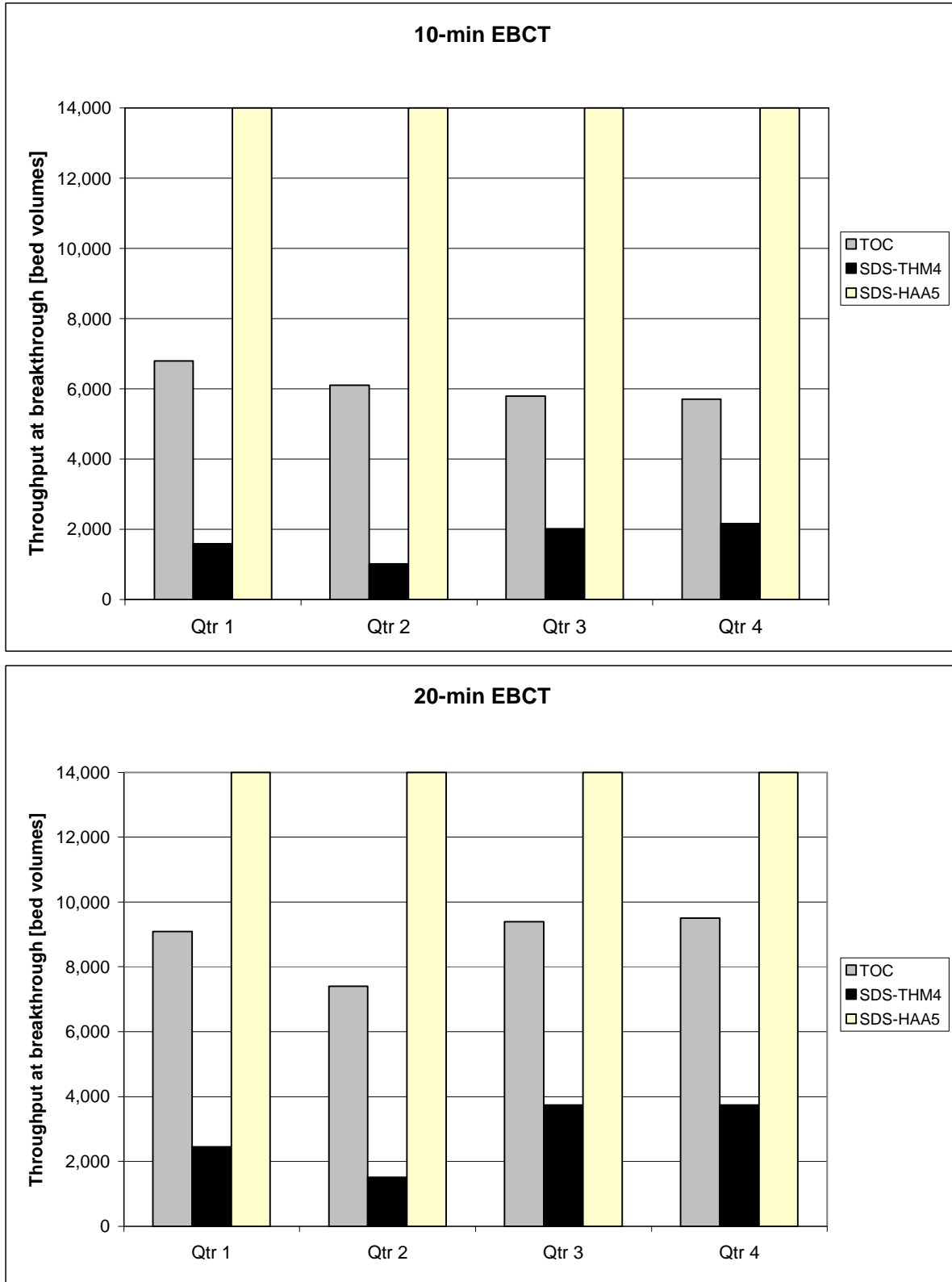
TABLE 4-3

RSSCT Breakthrough Times and Bed Volumes

Parameter	Breakthrough Criterion	10-Minute EBCT		20-Minute EBCT	
		Operation Time [full-scale equiv. days]	Throughput [bed volumes]	Operation Time [full-scale equiv. days]	Throughput [bed volumes]
1st Quarter					
TOC	2.74 mg/L ^a	47	6800	126	9100
SDS-THM4	40 µg/L	11	1584	34	2448
SDS-HAA5	30 µg/L	infinite ^b	infinite ^b	infinite ^b	infinite ^b
2nd Quarter					
TOC	3.34 mg/L ^a	42	6100	103	7400
SDS-THM4	40 µg/L	7	1008	21	1512
SDS-HAA5	30 µg/L	>100	>14,400	>200	>14,400
3rd Quarter					
TOC	3.15 mg/L ^a	40	5800	131	9400
SDS-THM4	40 µg/L	14	2016	52	3744
SDS-HAA5	30 µg/L	infinite ^b	infinite ^b	infinite ^b	infinite ^b
4th Quarter					
TOC	3.49 mg/L ^a	40	5700	132	9500
SDS-THM4	40 µg/L	15	2160	52	3744
SDS-HAA5	30 µg/L	infinite ^b	infinite ^b	infinite ^b	infinite ^b

^a 70% of influent TOC (i.e., 30% removal)^b Influent concentration was less than the breakthrough criterion, so breakthrough would never occur.

FIGURE 4-5
Breakthrough Comparison by Parameter



* Bars shown extending to 14,000 bed volumes are included for illustrative purposes and indicate that breakthrough would not occur (Quarters 1, 3, and 4) or may occur after a very long run time (Quarter 2).

FIGURE 4-6
Breakthrough Comparison by EBCT

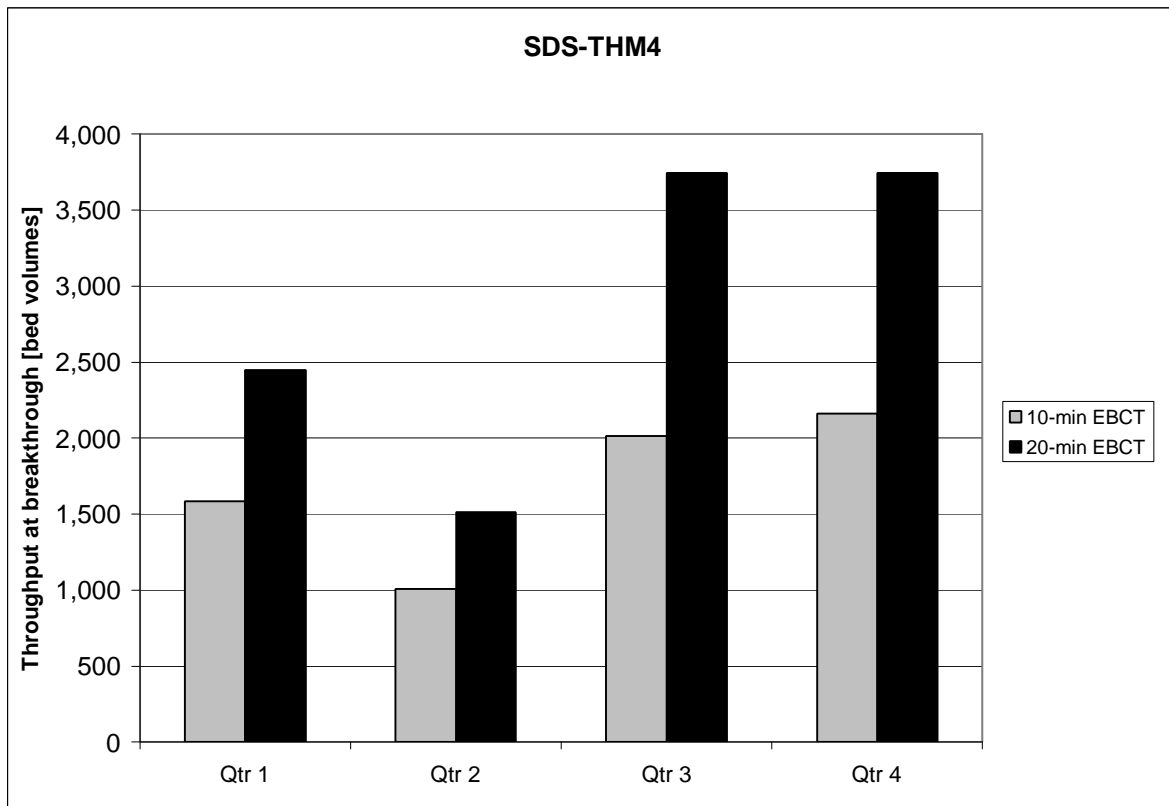


TABLE 4-4

RSSCT Effluent Water SDS Test Conditions

Parameter	1st Quarter (Feb-98)	2nd Quarter (Jun-98)	3rd Quarter (Aug-98)	4th Quarter (Nov-98)
10-min EBCT				
Average pH	8.93	8.29	8.37	8.48
Average temperature [°C]	8.0	26.0	25.0	16.2
Average contact time [hr]	7.16	4.23	2.01	4.38
Chlorine dose [mg/L]	1.00 - 1.80 Average: 1.41	1.54 - 3.08 Average: 2.47	0.97 - 2.16 Average: 1.76	1.20 - 2.60 Average: 2.06
Free chlorine residual [mg/L]	0.52 - 0.72 Average: 0.64	0.89 - 1.43 Average: 1.14	0.45 - 1.12 Average: 0.86	0.95 - 1.21 Average: 1.11
20-min EBCT				
Average pH	8.94	8.28	8.35	8.44
Average temperature [°C]	8	26	25	16
Average contact time [hr]	7.06	4.21	1.97	4.37
Chlorine dose [mg/L]	1.00 - 1.70 Average: 1.38	1.55 - 3.28 Average: 2.20	0.96 - 2.10 Average: 1.57	1.20 - 2.64 Average: 2.01
Free chlorine residual [mg/L]	0.62 - 0.97 Average: 0.75	0.52 - 1.66 Average: 1.02	0.41 - 1.11 Average: 0.69	0.80 - 1.23 Average: 1.08

FIGURE 4-7
RSSCT Influent TOC and DBP Precursors

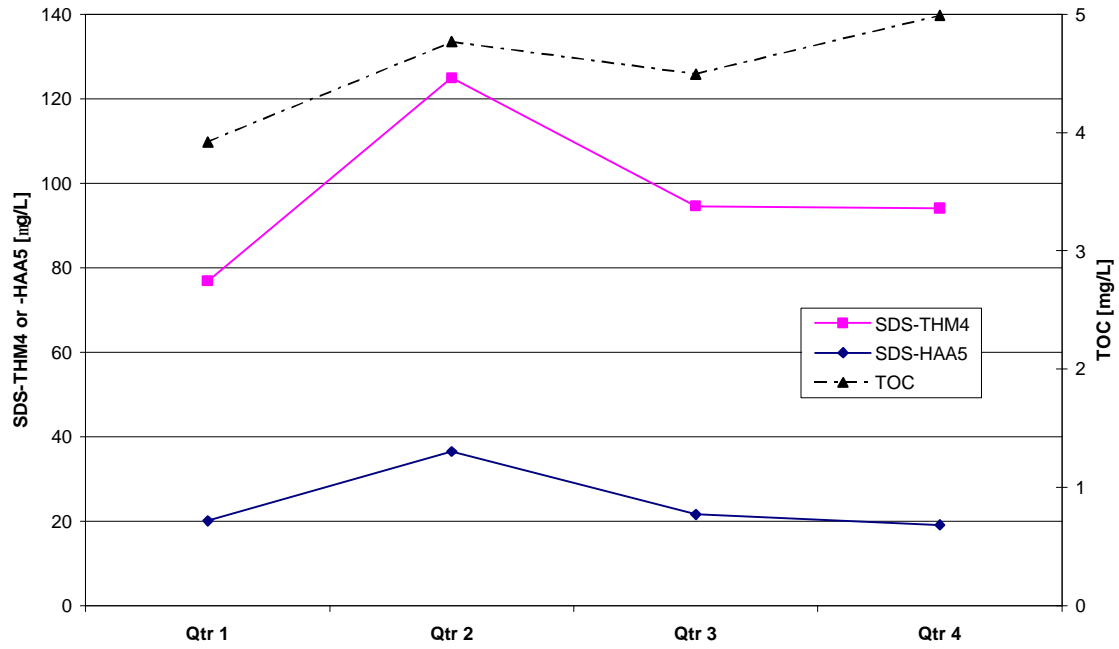


TABLE 4-5
Seasonal Variation in Carbon Usage Rates

Quarter (sampling date)	Est. Carbon Usage Rate for 20-min EBCT Bed [lb/MG]	Temperature [°C]	First Compounds to Break Through
1 st Quarter (Feb-98)	1,530	8.0	THM precursors
2 nd Quarter (Jun-98)	2,480	26	THM precursors
3 rd Quarter (Aug-98)	1,000	25	THM precursors
4 th Quarter (Nov-98)	1,000	16	THM precursors

5. QA/QC Summary

The QA/QC data for laboratory duplicates, laboratory fortified matrix samples, and independent QC checks (Performance Evaluation, or PE samples) are summarized in the *Treatment Study Summary Report Spreadsheets*, submitted in conjunction with this report. The calibration procedures used for bromide, TOC, TOX, UV254, THMs, and HAAs are summarized in Table 5-1. Calibration frequencies, calibration check standard concentrations, and calibration acceptance criteria specified in the *DPB/ICR Analytical Methods Manual* (EPA, 1996b) were followed.

TABLE 5-1
Calibration Procedures Summary

Parameter	Analytical Method	Initial Calibration	Continuing Calibration
Bromide	EPA 300.0	4-point calibration with point-to-point interpolation	Low-, mid-, and high-level calibration checks each analysis day; LCS
TOC	SM 5310 D	5-point calibration with linear fit	Low-, mid-, and high-level calibration checks each analysis day; LCS
TOX	SM 5320 B	Test titrations; cell checks within 3% of injected mass	Low-, mid-, and high-level calibration checks each analysis day
UV254	SM 5910	Blank; LCS	Low-, mid-, and high-level calibration checks each analysis day
THMs: CHCl ₃ , BDCM, DBCM, CHBr ₃	EPA 551.1	8-point calibration with point-to-point interpolation	Low-, mid-, and high-level calibration checks each analysis day; LCS
HAAs: BCAA, DBAA, DCAA, MBAA, MCAA, TCAA	SM 6251 B	5-point calibration with point-to-point interpolation	Low-, mid-, and high-level calibration checks each analysis day; LCS

LCS = lab control sample (secondary source standard)

6. References

EPA. 1996. ICR Manual for Bench- and Pilot-Scale Treatment Studies. EPA 814-B-96-003, April 1996a.

EPA. 1996. DBP/ICR Analytical Methods Manual. EPA 814-B-96-002, April 1996b.

EPA. 1997. ICR Treatment Studies Data Collection Spreadsheet User's Guide. EPA 815-B-97-002, April 1997.