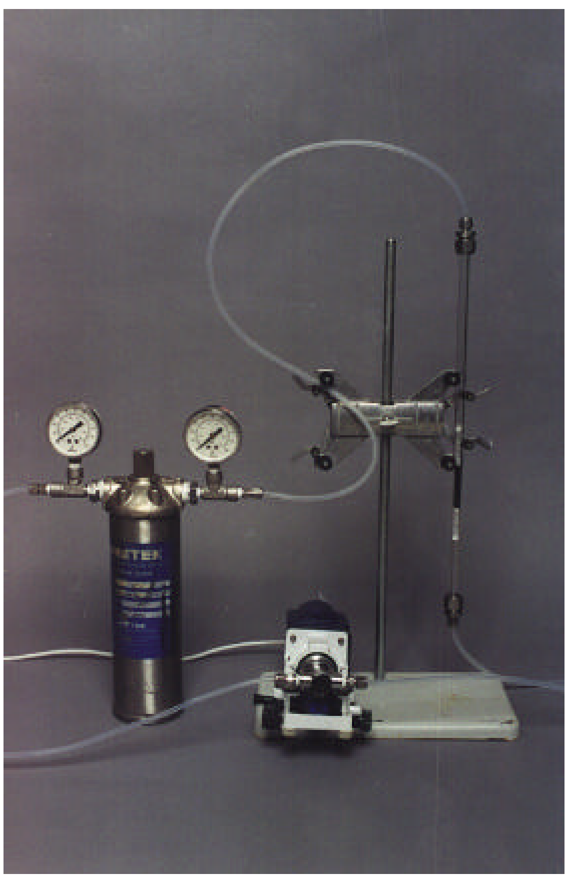
Final Report

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 May 19, 1998 to February 18, 1999



Submitted: July 9, 1999

Submitted by: **City of Cocoa**

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Claude H. Dyal Water Treatment Plant

ICR # 282

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

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Contents

1. Conclusions and Recommendations

Finished water quality data collected for the purposes of the Information Collection Rule (ICR) and submitted by the City of Cocoa's Claude H. Dyal Water Treatment Plant (WTP) are in compliance with the Stage 1 maximum contaminant levels (MCLs) for total trihalomethanes (TTHMs, or THM4) and haloacetic acids (HAA5). Annual average concentrations at distribution system monitoring points are 44.8 μg/L for THM4 and 20.4 μg/L for HAA5, compared to Stage 1 MCLs of 80 μg/L and 60 μg/L, respectively. The reported data would also be in compliance with the proposed Stage 2 MCL for HAA5 (30 μg/L) but not for THM4 (40 μg/L).

The results of this treatment study indicate that compliance with both the Stage 1 MCLs and the 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; (c) removal of color; and (d) allowing the use of chlorine for disinfection rather than chloramines (as currently practiced). 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 THMs would control carbon usage rates. 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 autumn and winter. Carbon requirements for those seasons were estimated to be 1,380 to 2,300 lbs/MG; whereas, spring and summer requirements may be only 25 to 70% of those usage rates. These carbon usage rates are quite high compared to rates experienced at many other water treatment plants employing GAC adsorption.

It may be possible to reduce carbon requirements by modifying WTP operations, such as minimizing free chlorine contact time and/or decreasing water pH before GAC treatment. It should also be noted that the effluent SDS tests conducted in this study tend to overestimate disinfection by-product (DBP) formation since free chlorine is used in the test procedure; whereas, the full-scale WTP uses chloramines for post-disinfection. This overestimation is directly related to the calculated carbon usage rates.

While GAC adsorption is an effective technology for controlling DBPs in finished drinking water, the cost associated with frequent carbon replacement/regeneration may make it impractical for implementation at the Dyal WTP. Alternate methods for controlling DBP formation include avoiding pre-chlorination, use of alternative disinfectants or oxidants, or membrane treatment. Membrane treatment may be more attractive than GAC because it can be used for both DBP control and hardness reduction. It is recommended that the City develop WTP-specific water quality goals, and then consider all practical options for achieving those goals prior to choosing a treatment strategy.

2. Background Information

2.1 Treatment Plant Description

The City of Cocoa, Florida, Claude H. Dyal Water Treatment Plant has a capacity of 48 MGD and serves approximately 157,000 people. Figure 2-1 presents a simplified schematic of the water treatment plant (WTP). The WTP treats groundwater from the Floridan aquifer using a process train consisting of air stripping, chemical softening, conventional filtration, and pre- and post-disinfection. Treatment plant design data are summarized in Table 2-1.

The main treatment challenges at the WTP are:

- Hydrogen Sulfide
- Hardness
- Disinfection
- Disinfection Byproducts

Hydrogen sulfide is removed from the water by air stripping and hardness is reduced by lime-soda softening. Disinfection for the removal of potential pathogens is a priority, and is performed at a number of points in the process train. Unfortunately, disinfection can and does produce unwanted byproducts. Disinfection byproduct formation is held in check at the plant by removing precursor material and using chloramines for post-chlorination.

2.2 Source/Finished Water Quality

Tables 2-2 and 2-3 summarize source and finished water quality characteristics for the Claude H. Dyal WTP for the period of January through December 1998 (the last 12 months of the 18-month ICR data collection period).

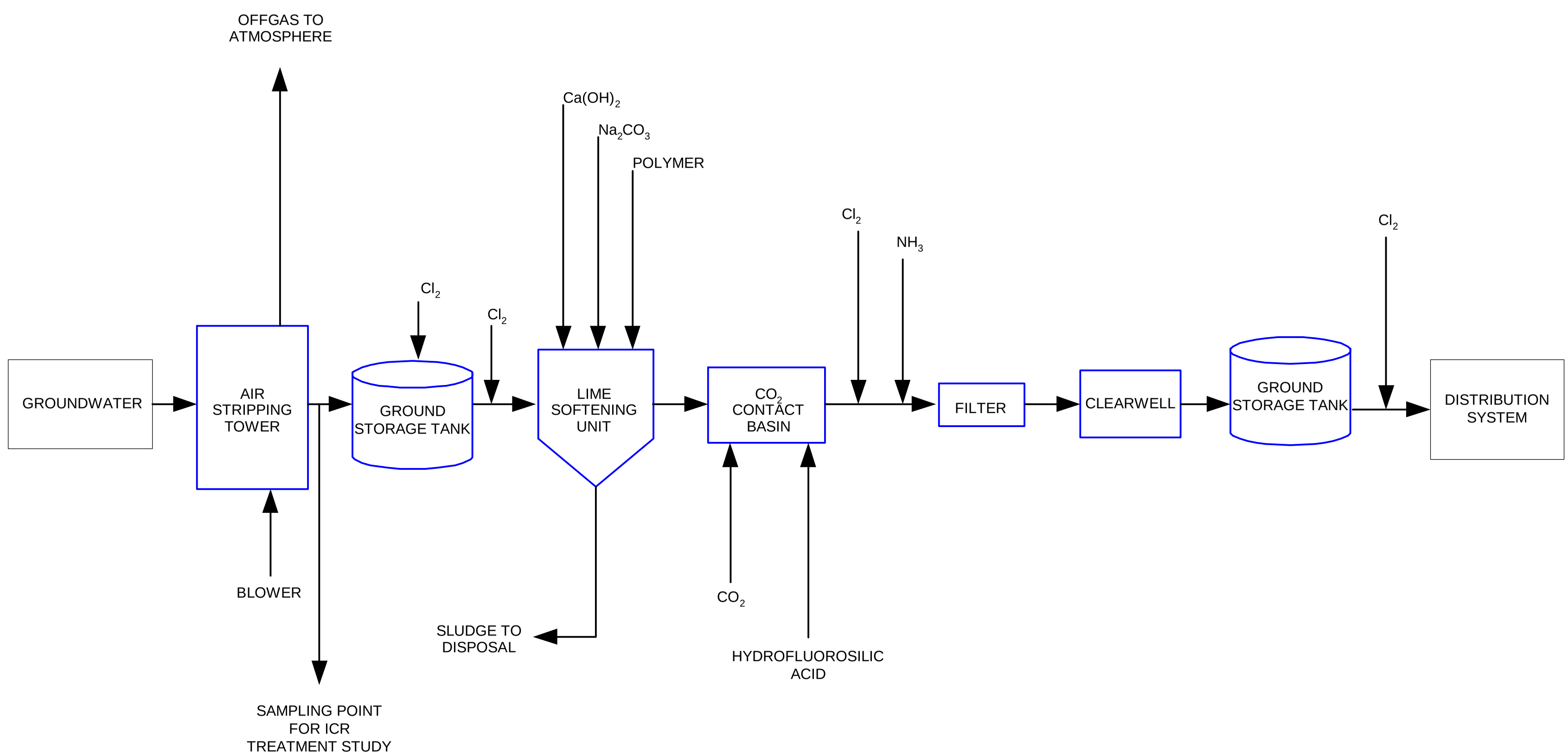

FIGURE 2-1
Claude H. Dyal Water Treatment Plant Schematic

TABLE 2-1

Water Treatment Plant Design Data

Unit Process	Process Description	
Packed Tower Air Stripping	Horizontal Cross Sectional Area (sf)	706
	Air Flow (SCFM)	64,000
Disinfection	Chemical Type	Chlorine Gas
	Dosage (mg/L as Cl_2)	4.0
Ground Storage	Liquid Volume (gallons)	3,000,000
Disinfection	Chemical Type	Chlorine Gas
	Dosage (mg/L as Cl_2)	1.5
Lime-Soda Softening	Clarifier Type	Solids Contact
	Liquid Volume (gallons)	1,170,000
	Type of Mixer	Mechanical
	Surface Area (sf)	7,854
	Baffling Type	Unbaffled-mix tank
	Coagulant Aid	Wispro Floc-N (Potato Starch)
	Coagulant Aid Dose (mg/L)	1.0
	Lime Dose (mg/L)	170
	Soda Ash Dose (mg/L)	65
Recarbonation	Surface Area (sf)	918
	Liquid Volume (gallons)	109,866
	Baffling Type	Superior-Serpentine
	Carbon Dioxide Dose (mg/l as CO_2)	20
	Hydrofluorosilic Acid Dose (mg/L as F)	0.6
Disinfection	Chemical Type	Chlorine Gas
	Dosage (mg/L as Cl2)	3.5
	Chemical type	Anhydrous Ammonia
	Dosage (mg/L as NH_3)	1.0
Filtration	Surface Area (sf)	8,358
	Liquid Volume (gallons)	243,876
	Total Media Depth (inches)	31
	Media Type	Dual - Anthracite/Sand
Clearwell	Surface Area (sf)	14,891
	Liquid Volume (gallons)	1,336,639
	Baffling Type	Unbaffled, in-out flow
	Covered contactor	yes
Ground Storage Finished Water	Surface Area (sf)	40,192
	Liquid Volume (gallons)	10,000,000
	Baffling Type	Unbaffled, in-out flow
Disinfection	Chemical Type	Chlorine Gas
	Dosage (mg/L as Cl_2)	0.5

TABLE 2-2

Source Water Quality

Water Quality Parameter	Units	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature	deg C	24.9	0.9	26.6	23.8
pH	pH units	7.46	0.12	7.65	7.30
Turbidity	ntu	0.8	1.0	3.3	0.2
Alkalinity	mg/L as CaCO3	207	6	215	200
Calcium Hardness	mg/L as CaCO3	252	49	287	102
Total Hardness	mg/L as CaCO3	319	46	349	180
TOC	mg/L	5.4	0.4	6.3	5.0
UV254	cm^{-1}	0.266	0.01	0.291	0.242
SUVA	L/(mg-m)	4.97	0.49	5.71	4.03
Bromide	µg/L	0.31	0.04	0.37	0.25

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	deg C	24.7	1.4	27.3	22.4
pH	pH units	8.71	0.20	9.09	8.46
Turbidity	ntu	0.11	0.04	0.20	0.05
TOC	mg/L	3.6	0.3	4.2	3.3
UV254	cm^{-1}	0.107	0.006	0.116	0.098
SUVA	L/(mg-m)	2.96	0.22	3.42	2.65
DS-THM4	µg/L	44.8	20.4	74.1	27.3
DS-HAA5	µg/L	20.4	6.1	27.9	13.4

SUVA = specific ultraviolet absorbance = UV254*100/TOC

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

3. Materials and Methods

3.1 Pretreatment

The water was collected following air stripping but prior to disinfection to avoid the presence of chlorine in the test water sample. Pretreatment was designed to simulate chemical treatment and TOC removal via lime-soda softening at the WTP. Pretreatment prior to advanced treatment process testing consisted of coagulation, flocculation, sedimentation, recarbonation, and filtration. Coagulation, 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 lime, soda ash, and Wispro Floc-N (coagulant aid) used in pretreatment were matched to those used at the WTP on the date each quarterly sample was collected. Figure 3-1 presents a schematic of the first three pretreatment processes, and Table 3-1 summarizes pretreatment design information. Following sedimentation, the clarified water was decanted, recarbonated to reduce pH by bubbling CO_2 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-μm pore size) installed upstream from the bench-scale carbon columns.

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 presents 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.

Preparing Carbon

Calgon F-300 carbon was prepared for use in the RSSCTs. 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.

Pack Column and Test Integrity

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).

Start-up and Operation

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 (MRLs). 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 Number: ICROR001

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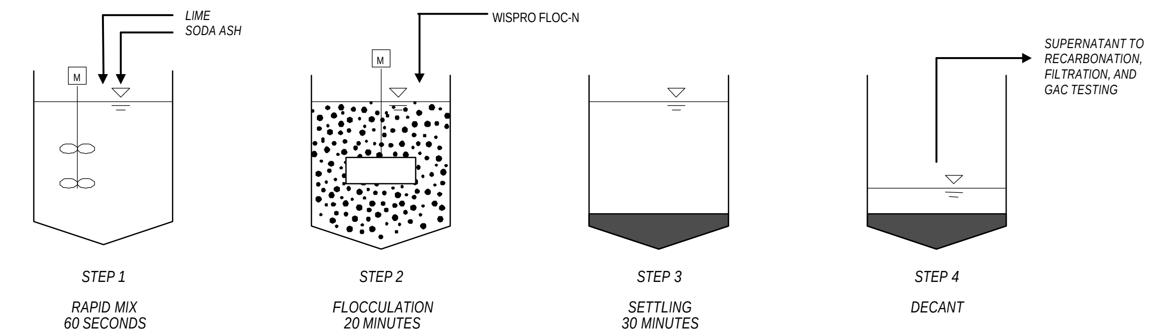


FIGURE 3-1
Schematic of Bench-Scale Pretreatment Processes

TABLE 3-1
Pretreatment Design Data

Unit Process	Process Description			
	1st Quarter (Apr-98)	**2nd Quarter (Jul-98)**	**3rd Quarter (Sep-98)**	**4th Quarter (Jan-99)**
Coagulation				
Lime Dose (mg/L)	166	231	60	170
Soda Ash Dose (mg/L)	48	0	65	64
Coagulation pH[a]	11.1	10.5	9.5	10.1
Rapid Mix Time (min)	1.0	1.0	1.0	1.0
Flocculation				
Wispro Floc Dose (mg/L)	0.93	1.03	0.84	0.98
Flocculation Time (min)	20	20	20	20
Sedimentation				
Settling Time (min)	30	30	30	30
Recarbonation				
pH after CO_2 addition	8.6	8.8	8.9	8.8
Filtration				
Teflon cartridge filter pore size (μm)	0.1	0.1	0.1	0.1

[a] pH after chemical addition

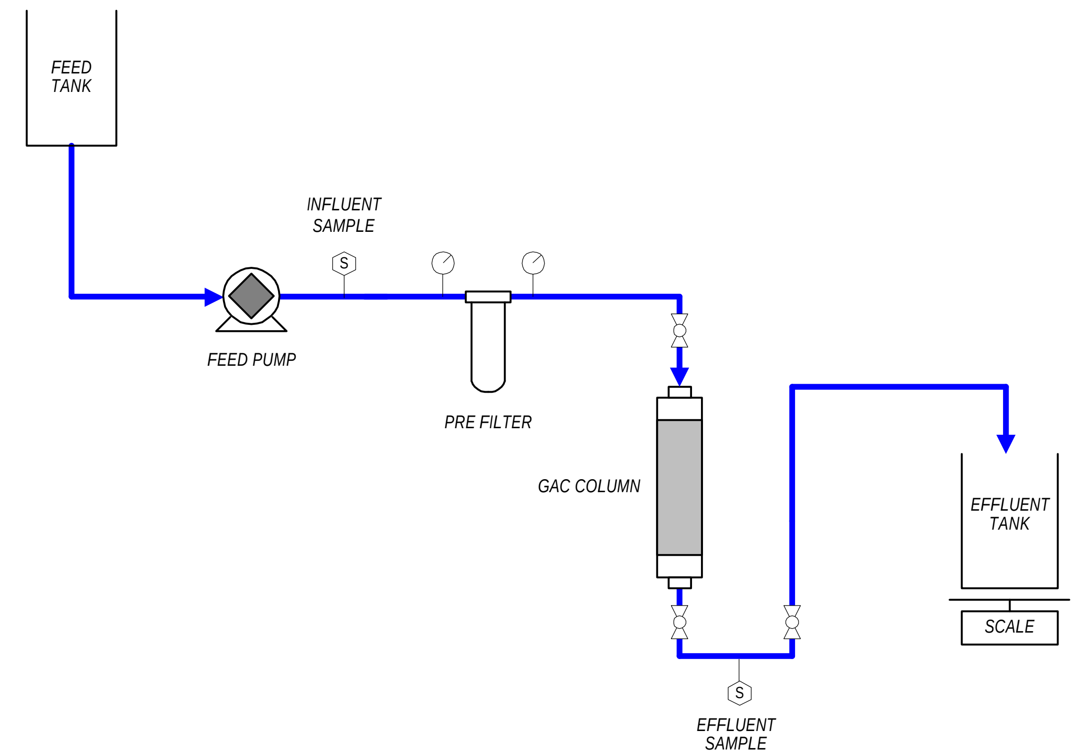


FIGURE 3-2
Schematic of RSSCT Apparatus

TABLE 3-2
RSSCT Design Data

Input Design Parameters	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr
RSSCT influent TOC (mg/L)	3.9	4.8	5.4	5.2
Inner diameter of the RSSCT column, D_{SC} (mm)	8.0	8.0	8.0	8.0
Minimum RSSCT Reynolds number, $Re_{SC, min}$	0.501	0.501	0.501	0.501
Full-scale operating temperature, T^oC (^oC)	24.2	26.8	26.8	24.0
Full-scale bed porosity, e_{LC}	0.42	0.42	0.42	0.42
Measured RSSCT dry bed density, r_{SC} (g/cm^3)	0.56	0.46	0.44	0.44
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}	3650	2863	2447	2570
Estimated run length, BV_T (= 2 x BV_{50})	7300	5725	4893	5141
BV_T + 30% safety factor, $BV_{T+30\%}$ (= 2.6 x BV_{50})	9490	7443	6361	6683
General RSSCT Design Parameters				
Kinematic viscosity at T^oC, n_{LC} (m^2/s)	9.278E-07	8.727E-07	8.727E-07	9.322E-07
RSSCT carbon particle diameter, d_{SC} (mm)	0.2150	0.2150	0.2150	0.2150
Scaling factor, SF	6.88	6.88	6.88	6.88
RSSCT hydraulic loading rate, v_{SC} (m/hr)	3.27	3.07	3.07	3.28
RSSCT flow rate, Q_{SC} (mL/min)	2.74	2.58	2.58	2.75
Estimated total influent volume required, V_{SC}^T (L)	113	84	71	80
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)	66	52	44	46
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	1.45	1.45	1.45	1.45
Estimated RSSCT run time, t_{SC}^T (days)	9.57	7.51	6.42	6.74
RSSCT bed length, l_{SC} (cm)	7.9	7.4	7.4	8.0
Estimated volume required for 10-minute EBCT, V_{SC} (L)	38	28	24	27
Mass GAC required, m_{SC} (g)	2.23	1.72	1.66	1.77
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)	132	103	88	93
RSSCT empty bed contact time, $EBCT_{SC}$ (min)	2.91	2.91	2.91	2.91
Estimated RSSCT run time, t_{SC}^T (days)	19.15	15.02	12.83	13.48
RSSCT bed length, l_{SC} (cm)	15.8	14.9	14.9	15.9
Estimated volume required for 20-minute EBCT, V_{SC} (L)	76	56	48	53
Mass GAC required, m_{SC} (g)	4.46	3.44	3.32	3.54

TABLE 3-3
RSSCT Experimental Design

Season	Pretreatment	EBCT [min]
1st Quarter (Spring)	Softening	10 & 20
2nd Quarter (Summer)	Softening	10 & 20
3rd Quarter (Autumn)	Softening	10 & 20
4th Quarter (Winter)	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]
NH_3-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 NH3-N
Calcium Hardness	EPA 200.7	5 mg/L as CaCO3
Total Hardness	SM 2340 D	5 mg/L as CaCO3
Bromide	EPA 300.0	10 µg/L
Alkalinity	SM 2320 B	5 mg/L as CaCO3
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 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. TOC, UV254, SDS-TOX, SDS-THM, and SDS-HAA concentrations were lowest in the 1st Quarter (April) and highest in the 3rd and 4th Quarters (September and January). Turbidity was highest in the 4th Quarter. Elevated TOC, SDS-THM, and SDS-HAA concentrations are important because higher levels of these parameters result in faster exhaustion of GAC. Turbidity normally does not affect the rate of GAC exhaustion. Elevated turbidity increases the rate of head loss build-up; however, 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 48-hr contact time. 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 6 out of 10 cases (60%) this goal was met. One 2nd Quarter sample was below this range and one 3rd Quarter sample and two 4th Quarter samples were above 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 appears to have been roughly correlated with feed water TOC. The Stage 1 MCLs for THM4 and HAA5 are 80 and 60 μg/L, respectively. The influent water SDS-THM4 concentrations exceeded the regulatory level in all four quarters and the influent water SDS-HAA5 concentrations exceeded the regulatory level in the 4th Quarter.

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 = 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 µg / L for THM4 and 30 µg / 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-THM4, 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. In all four quarters, THM precursors broke through the carbon sooner than HAA precursors; therefore, SDS-THM4 would dictate regeneration requirements (see Figure 4-5). SDS-THM4 breakthrough was particularly rapid in the 3rd and 4th Quarters of testing.

The data also indicate that there would be some benefit to using a 20-min EBCT GAC adsorber over a 10-min EBCT adsorber. The 20-min EBCT system treated approximately 1.2 to 5.6 times more bed volumes before SDS-THM4 breakthrough than the 10-min system in the four quarters of testing (refer to Figure 4-6). To reiterate, 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 48-hr contact time. 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 49 out of 106 cases (49%) this goal was met. EPA does <u>not</u> consider a residual outside the target range to constitute a failure of the SDS test.

4.4 Impact of Seasonal Variability

GAC service life until breakthrough varied considerably over the four quarters of testing. Table 4-1 reveals that influent TOC, SDS-THM4, and SDS-HAA5 peaked in the 3rd and 4th Quarters (autumn and winter). Variations in these parameters are shown in Figure 4-7. It is difficult to tell whether the elevated TOC in the 3rd and 4th Quarters resulted from actual seasonal variations in groundwater quality or from differences in chemical treatment in the softening process.

Figures 4-5 and 4-6 illustrate the seasonal variability in the volume of water that could be treated before breakthrough of DBP 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 autumn and winter. 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 3rd and 4th Quarter carbon requirements from 2,300 to 1,380 lbs/MG. Even so, this would be a markedly high carbon usage rate.

TABLE 4-1
RSSCT Influent Water Quality

Parameter	Units	1st Quarter (Apr-98) Average [CV %]	2nd Quarter (Jul-98) Average [CV %]	3rd Quarter (Sep-98) Average [CV %]	4th Quarter (Jan-99) Average [CV %]
Alkalinity*	mg/L as $CaCO_3$	88.5	59.0 [10.17]	145 [2.08]	99.8 [0.501]
Total hardness*	mg/L as $CaCO_3$	156	207 [7.26]	244 [2.87]	139 [12.3]
Calcium hardness*	mg/L as $CaCO_3$	151	143 [7.72]	170 [2.95]	80.5 [11.4]
Ammonia*	mg/L as N	0.335	BMRL	BMRL	0.350
Bromide*	μg/L	330	323 [4.95]	367 [3.00]	276 [4.73]
pH	pH units	8.29 [3.24]*	8.43 [6.12]	8.40 [0.56]	8.62 [1.44]
Turbidity	ntu	0.145 [24.4]*	0.270 [102.9]	0.097 [41.8]	0.977 [87.3]
Temperature	^oC	20.0 [0.00]*	20.0 [0.00]	20.0 [0.00]	21.3 [2.71]
TOC	mg/L	3.41 [3.53]*	4.07 [9.07]	5.28 [3.15]	5.38 [1.49]
UV254	cm^{-1}	0.079 [13.02]*	0.109 [0.917]	0.147 [0.680]	0.155 [1.71]
SUVA	L/(mg-m)	2.32 [16.51]*	2.70 [10.31]	2.79 [3.07]	2.88 [0.571]
SDS-Cl2 demand	mg/L	6.39	5.75 [10.02]	7.58 [7.04]	7.29 [8.77]
SDS-TOX	μg/L as Cl^-	198	366 [16.13]	568 [3.89]	497 [3.28]
SDS-THM4	μg/L	164	178 [22.31]	260 [9.14]	224 [3.26]
SDS-HAA5	μg/L	24.1	39.5 [8.39]*	50.0 [4.93]	66.0 [11.3]
SDS-HAA6	μg/L	33.3	54.1 [7.81]*	66.4 [4.77]	80.5 [10.0]

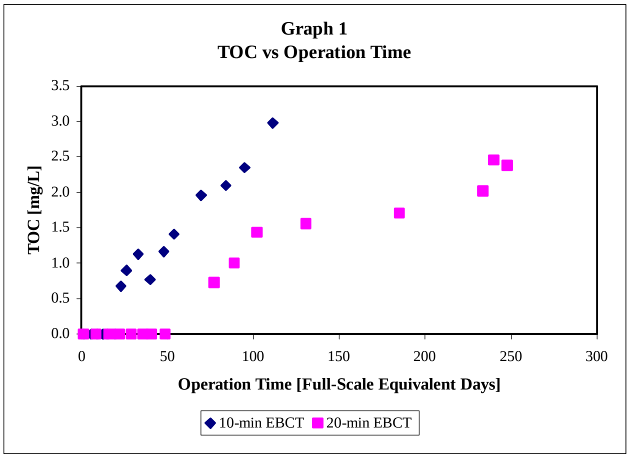
BMRL = Below Minimum Reporting Level
SDS = Simulated distribution system
SUVA = Specific ultraviolet absorbance = UV254*100/TOC
CV = Coefficient of variation =(standard deviation/mean)(100%)
* For these parameters, values in brackets represent Relative Percent Difference(RPD), defined as
[(Sample 1 - Sample 2)/Sample Average] x 100%

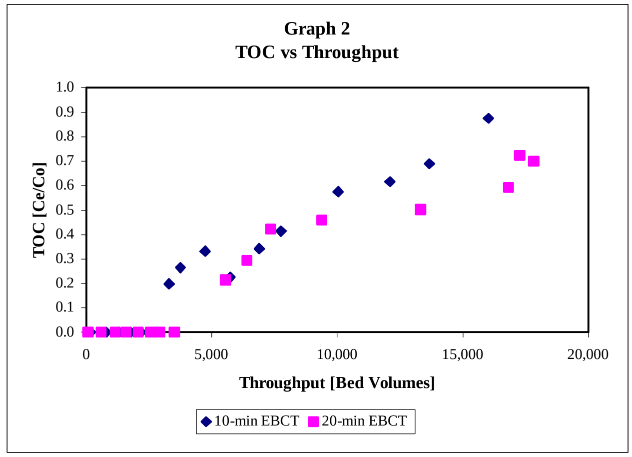
TABLE 4-2
RSSCT Influent Water SDS Test Conditions

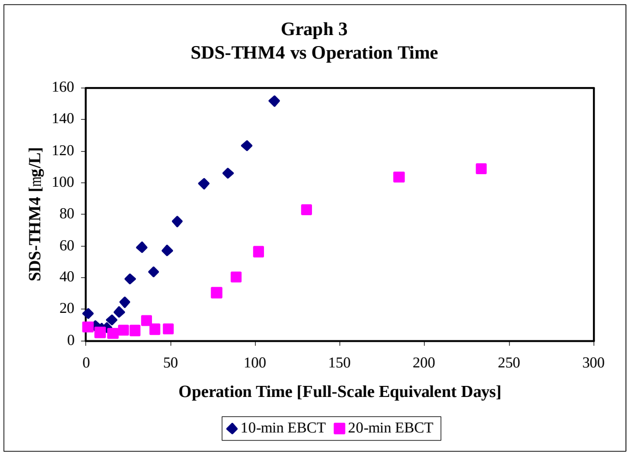
Parameter	1st Quarter (Apr-98)	2nd Quarter (Jul-98)	3rd Quarter (Oct-98)	4th Quarter (Jan-99)
Average pH	8.47	8.39	8.84	8.81
Average temperature [^oC]	25	25	27	25
Average contact time [hr]	49.1	47.7	47.8	48.3
Chlorine dose [mg/L]	6.30	6.27	8.69	8.75
Free chlorine residual [mg/L]	0.48	0.03 - 1.12 Average: 0.52	0.72 - 1.49 Average: 1.11	1.10 - 1.78 Average: 1.46

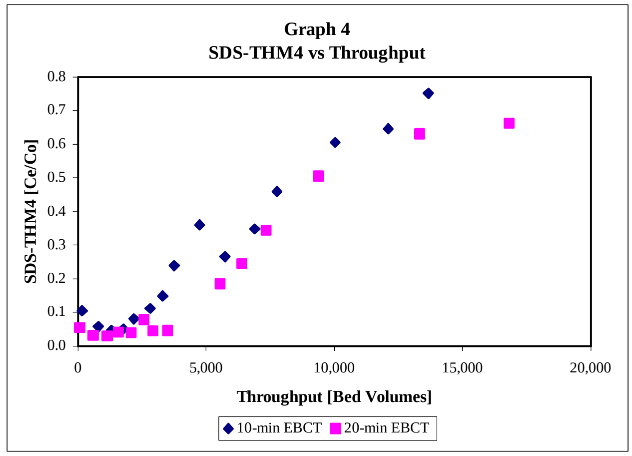
FIGURE 4-1

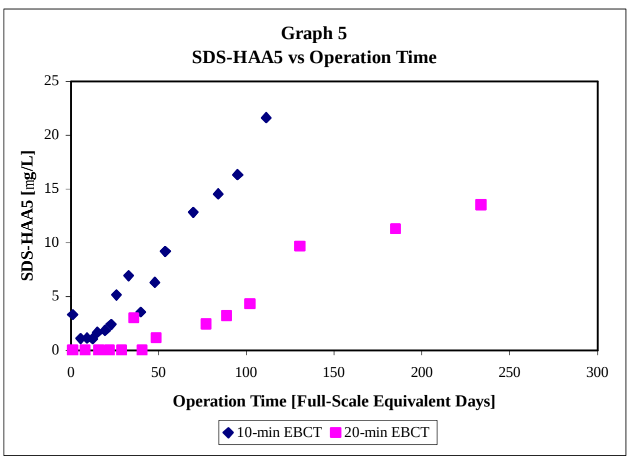
1st Quarter Breakthrough Curves











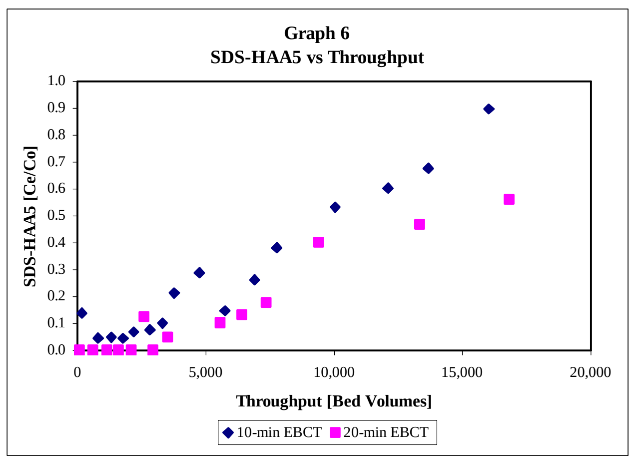


FIGURE 4-2

2nd Quarter Breakthrough Curves

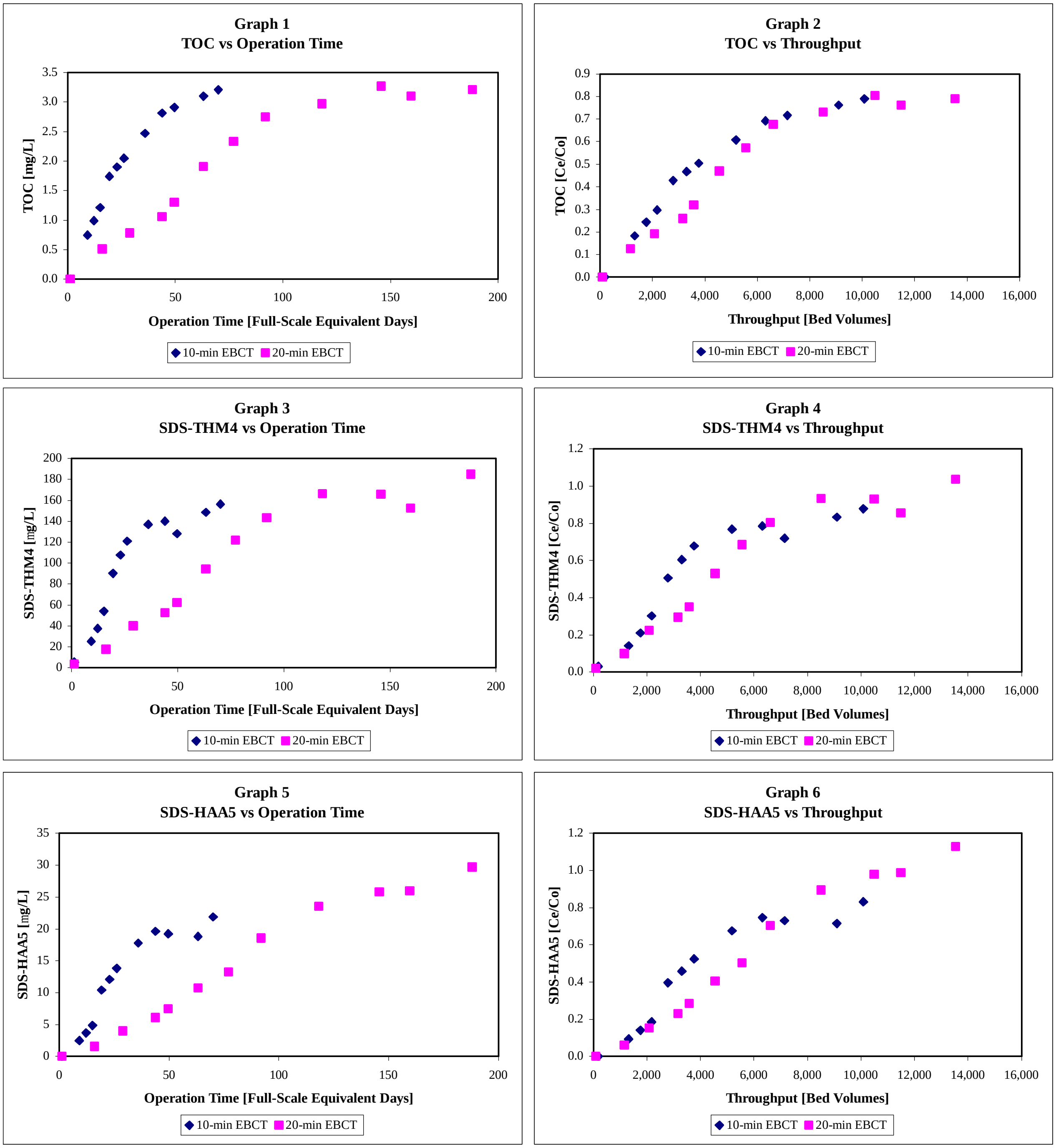


FIGURE 4-3

3rd Quarter Breakthrough Curves

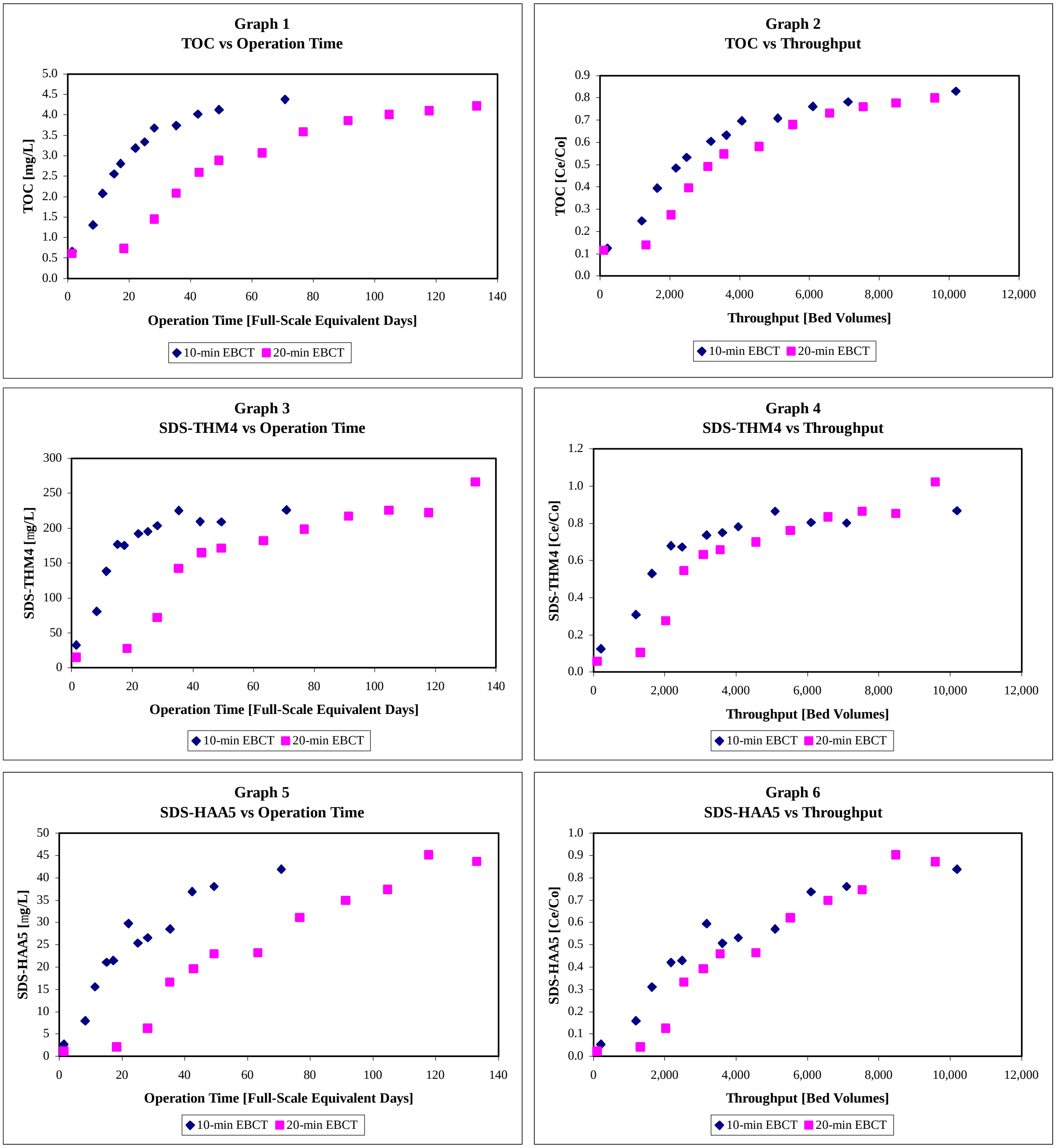
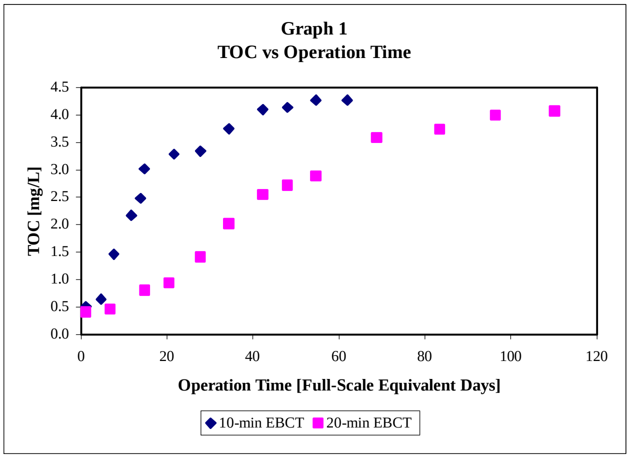
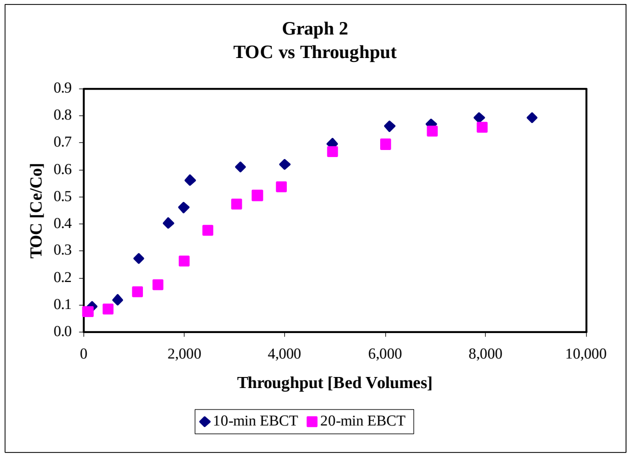
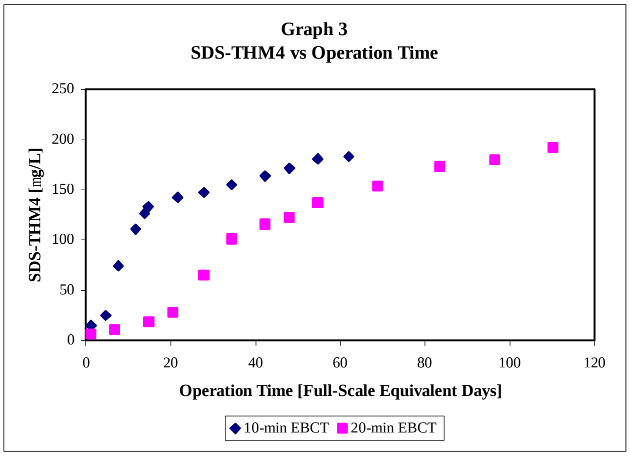


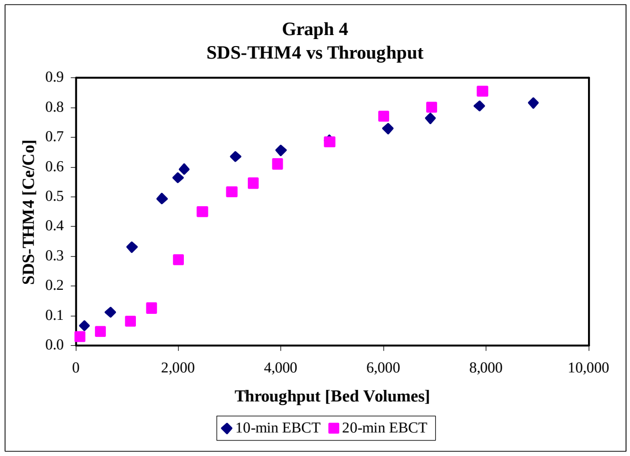
FIGURE 4-4

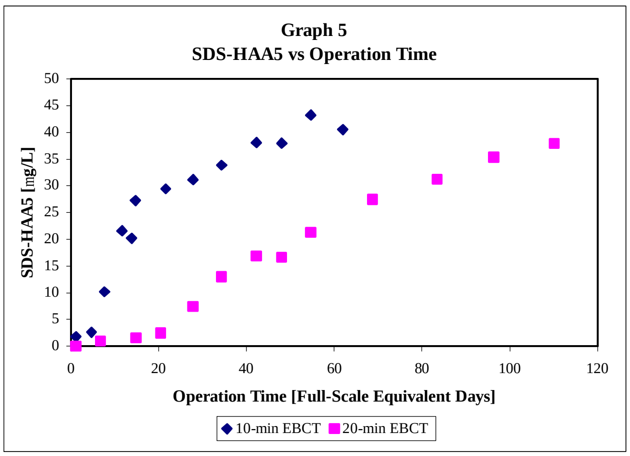
4th Quarter Breakthrough Curves











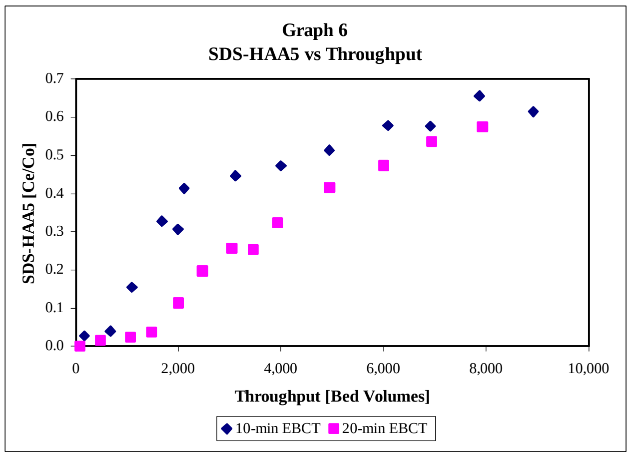


TABLE 4-3

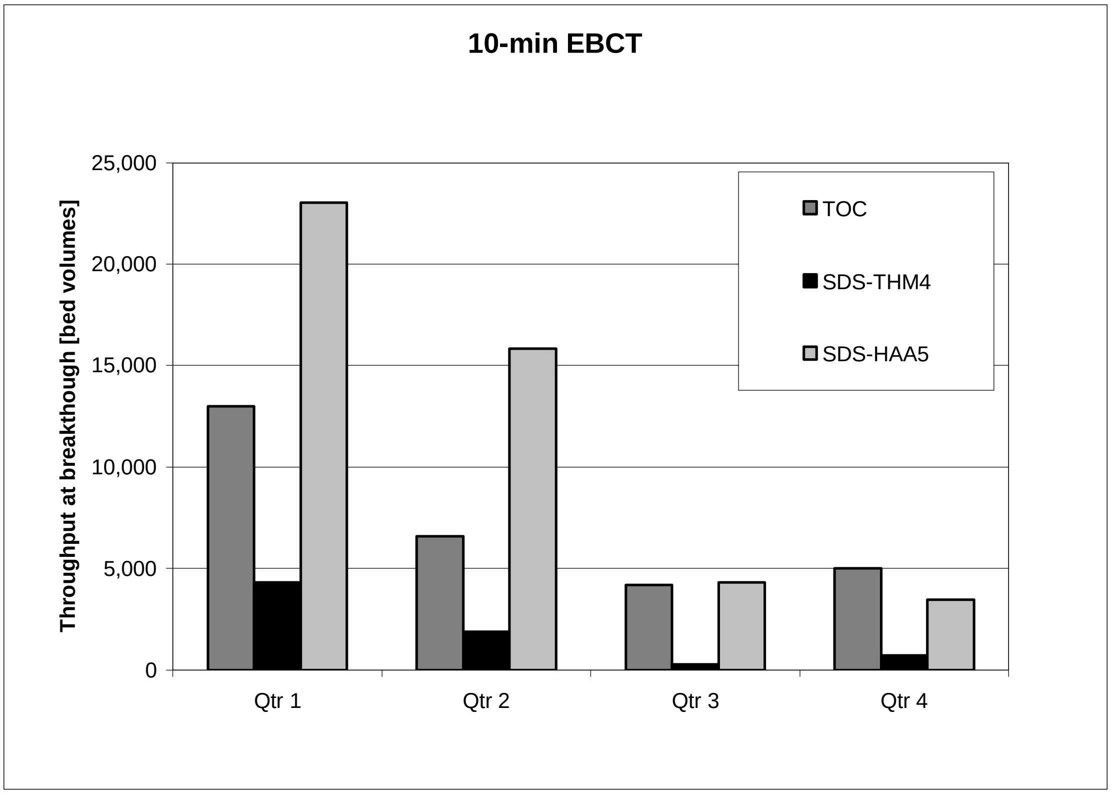
RSSCT Breakthrough Times and Bed Volumes

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	2.38 mg/L[a]	90	13,000	243	17,500
SDS-THM4	40 µg/L	30	4,320	87	6,260
SDS-HAA5	30 µg/L	160	23,040	> 365	> 26,280
2nd Quarter					
TOC	2.85 mg/L[a]	46	6,600	103	7,400
SDS-THM4	40 µg/L	13	1,870	32	2,300
SDS-HAA5	30 µg/L	110	15,840	190	13,680
3rd Quarter					
TOC	3.70 mg/L[a]	29	4,200	80	5,750
SDS-THM4	40 µg/L	2	288	22.5	1,620
SDS-HAA5	30 µg/L	30	4,320	75	5,400
4th Quarter					
TOC	3.77 mg/L[a]	35	5,000	82	5,900
SDS-THM4	40 µg/L	5	720	23	1,660
SDS-HAA5	30 µg/L	24	3,460	81	5,830

[a] 70% of influent TOC (i.e., 30% removal)

FIGURE 4-5

Breakthrough Comparison by Parameter



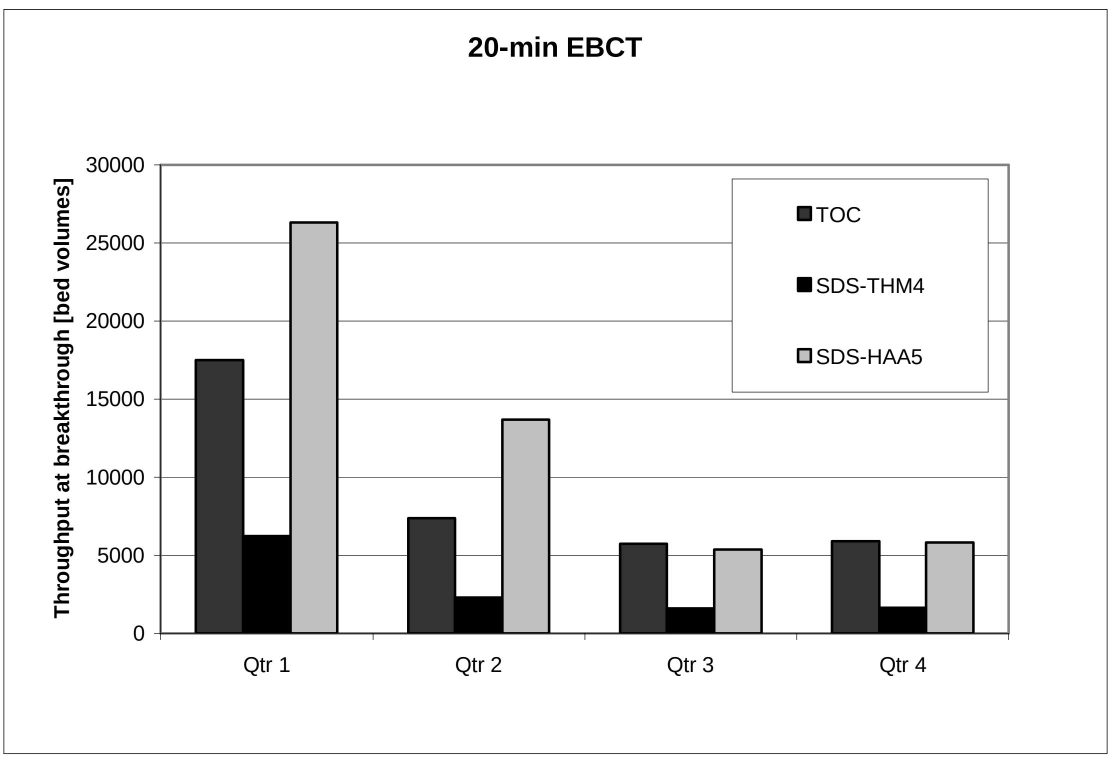
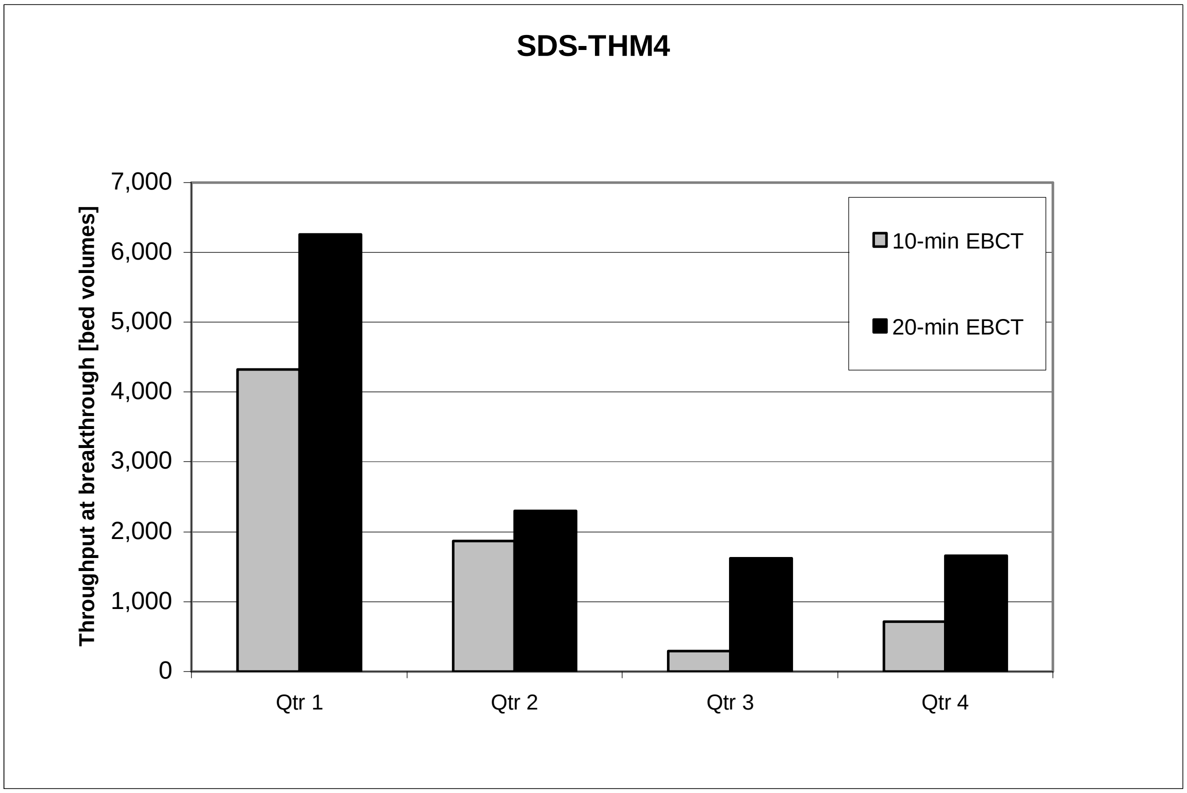


FIGURE 4-6

Breakthrough Comparison by EBCT



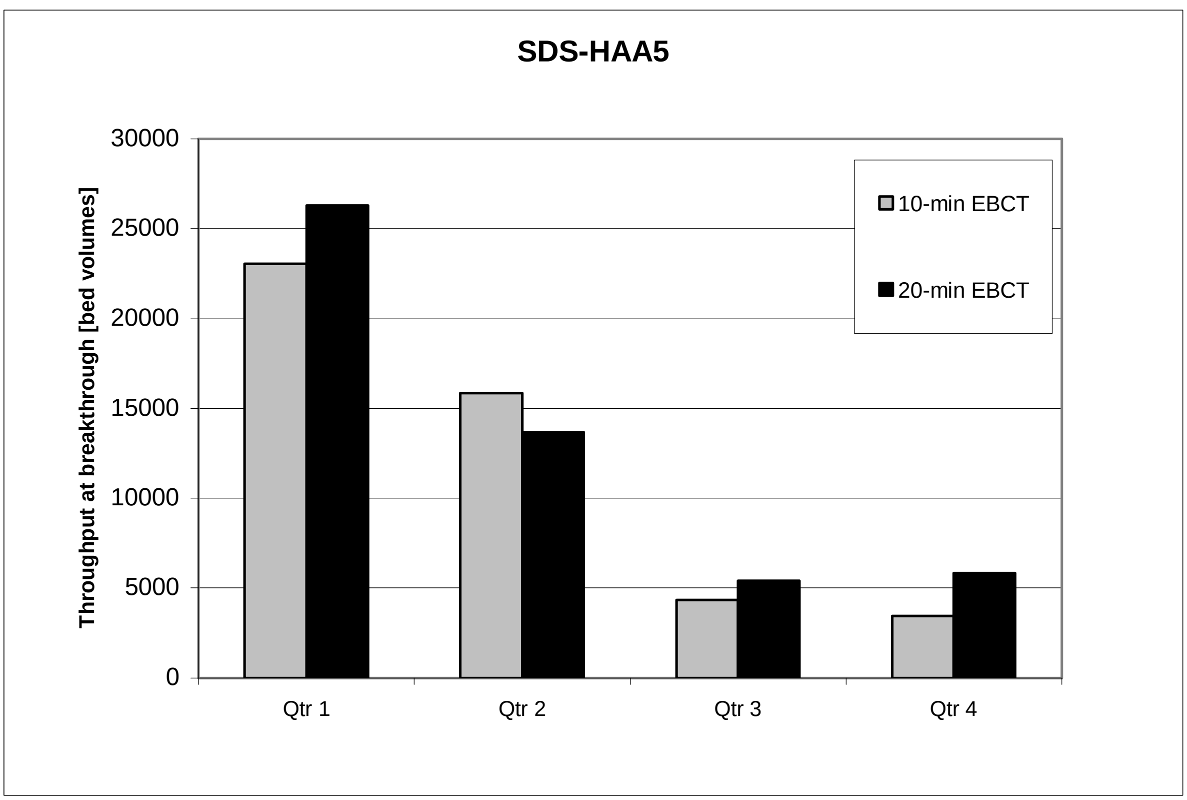


TABLE 4-4

RSSCT Effluent Water SDS Test Conditions

Parameter	1st Quarter (Apr-98)	2nd Quarter (Jul-98)	3rd Quarter (Oct-98)	4th Quarter (Jan-99)
		10-min EBCT		
Average pH	8.40	8.40	8.90	8.75
Average temperature [^{o}C]	24.3	23.6	27.4	24.9
Average contact time [hr]	47.21	46.57	47.71	48.00
Chlorine dose [mg/L]	4.30 - 5.70 Average: 4.66	2.11 - 4.50 Average: 3.56	3.50 - 7.51 Average: 5.79	3.40 - 7.60 Average: 5.96
Free chlorine residual [mg/L]	0.34 - 1.66 Average: 1.11	0.44 - 0.90 Average: 0.70	0.66 - 1.18 Average: 0.98	0.72 - 2.15 Average: 1.38
		20-min EBCT		
Average pH	8.41	8.37	8.89	8.76
Average temperature [^{o}C]	24.5	24.3	27.8	24.9
Average contact time [hr]	46.79	46.58	47.09	47.77
Chlorine dose [mg/L]	4.10 - 6.35 Average: 4.70	2.07 - 4.93 Average: 3.52	2.70 - 7.40 Average: 5.49	3.28 - 6.88 Average: 5.21
Free chlorine residual [mg/L]	0.37 - 1.57 Average: 1.08	0.43 - 1.48 Average: 0.93	0.64 - 2.06 Average: 1.29	0.92 - 3.22 Average: 1.97

FIGURE 4-7
RSSCT Influent TOC and DBP Precursors

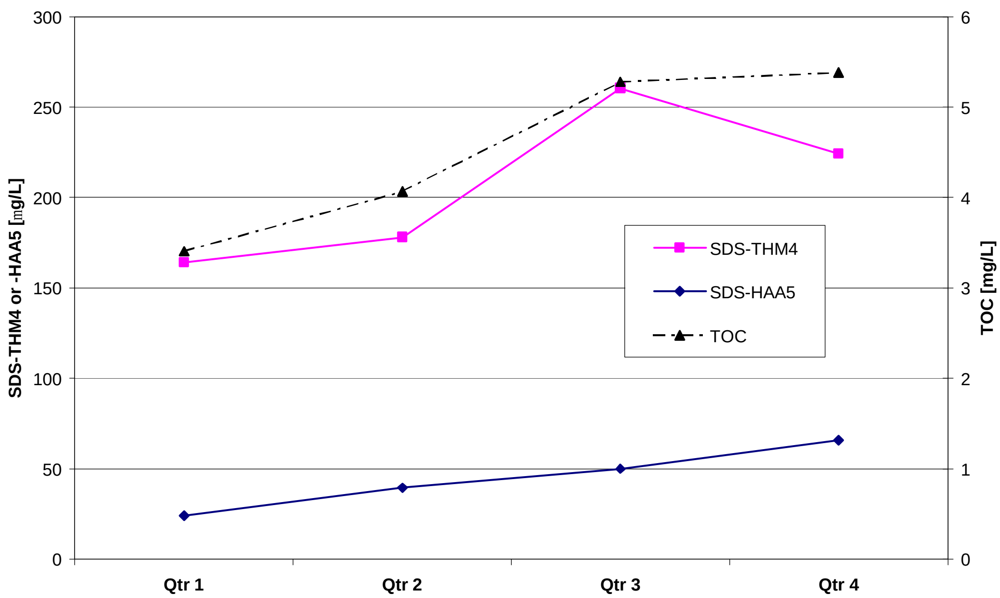


TABLE 4-5
Seasonal Variation in Carbon Usage Rates

Quarter (sampling date)	Est. Carbon Usage Rate for 20-min EBCT Bed [lb/MG]	Temperature [°C]	First Compounds to Break Through
1st Quarter (Apr-98)	600	24	THM precursors
2nd Quarter (Jul-98)	1,600	24	THM precursors
3rd Quarter (Oct-98)	2,300	27	THM precursors
4th Quarter (Jan-99)	2,300	25	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: CHCl3, BDCM, DBCM, CHBr3	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. 1996a. *ICR Manual for Bench- and Pilot-Scale Treatment Studies*. EPA 814-B-96-003, April 1996.

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

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