ICR Treatment Study Summary Report

Evaluation of Granular Activated Carbon Adsorption Technique Using Rapid Small Scale Column Bench-Scale Test for compliance with the Information Collection Rule

Conducted during the period of April 17, 1998 through March 4, 1999

Prepared by:
Mt.Carmel Water Treatment Laboratory
Waco, TX 76710

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For
City of Waco Water Department, PWSID# TX1550008
2905 Mt. Carmel Dr
Waco, TX 76710
(254)751-8554
(254)772-7909

Mt. Carmel Water Treatment Plant, Plant ICR # 639

Attachments:(**Fill up the # of disks)** diskettes containing the *Data Collection Spreadsheets, Treatment Study Summary Report*

Treatment Study Summary Report

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I. Conclusions and Recommendations

The GAC Bench scale study shows, GAC adsorption technique is a promising, and cost effective best available advanced treatment technology for the city of Waco. Conventional treatment seems to be working to meet the current regulations. For the stage II DBP Rule and the Enhanced Surface Water Treatment Rule (ESWTR) GAC adsorption would reduce the chlorine dosage and chlorination by-products by removing TOC in the raw water. At present the renovation of Mt. Carmel water treatment plant (#639) is possible, but for Plant # 640 (Riverside water treatment plant) there is no place for expansion. The best possible solution would be to modify the raw water station. The raw water should be free of chlorine, before it enters the GAC filter media. The reason for this is, once chlorine is added, it would react with organic carbon and produce trihalomethane. Trihalomethane will not be effectively adsorbed by GAC . Besides, the whole point of this treatment is to remove TOC and thus reduce the chlorine dosage in order to reduce DBPs. This will also reduce the coagulant addition. Chlorine should be added to the GAC effluent and pumped to both plants as usual.

Enhanced coagulation prior to GAC adsorption may be a possible technique to remove TOC, before the raw water enters in to the GAC bed . That would increase the bed life.

Blending of GAC filtered water and conventionally treated water and still have the trihalomethane level below 40 μg/L would also increase the bed life and cost effective.

II. Background Information

Waco is a city in Texas with an approximate population of 120,000. The current raw water supply is obtained from Lake Waco, which is fed by three tributaries, the North Bosque, the South Bosque and Hog Creek. The raw water is treated at Mt. Carmel and Riverside water treatment plants. This ICR treatment study was conducted at and for the Mt. Carmel treatment plant. Mt. Carmel plant is a conventional treatment plant with slow and fast mix coagulation chambers, flocculation, primary and secondary sedimentation units and Rapid sand filtration units. The plant was also designed to provide disinfection, pH adjustment, and fluoridation.

- **Treatment Plant Description**

The capacity of Mt. Carmel plant is 42 million gallons per day (MGD).

It consists of four separate, identical pretreatment trains. Each train has one first stage rapid mix basin, one first stage flocculation basin, one first stage sedimentation basin, and one second stage sedimentation basin. The settled water from each pretreatment train is collected in a common settled water flume, which feeds 16 gravity filters.

- **Treatment plant schematic**

The simple schematic of the existing treatment plant is shown in **Figure 1.**

- **Treatment plant design parameters**

Table 1 and **Table 2** depicts the summary of basic engineering, and chemical data for each unit process.

Table 1- Design Plant Chemical Parameters

Unit Process	Process Description	Chemical Name	Dose Rate (mg/L)
Disinfection	Chemical type: Chlorine Gas Measurement formula: Cl_2 Dose Rate(mg/L): 6.00	Chlorine Gas	6.00
	Chemical type: Anhydrous Ammonia Measurement formula: NH_3OH Dose Rate(mg/L): 1.30	Anhydrous Ammonia	1.30
	Chemical type: Chlorine Gas Measurement formula: Cl_2 Dose Rate(mg/L): 6.70	Chlorine Gas	6.70
Rapid Mix	Type of Mixer: Mechanical Baffling Type: Unbaffled- Mixed Tank Liquid Volume(gal): 50,864 Mean Velocity Gradient(sec^{-1}): 384.0	Powered Activated Carbon (PAC) Aqualum (ALUM)	3.00 21.00
Flocculation	Type of Mixer: Mechanical Liquid Volume(gal): 865,705 Baffling Type: Poor Stage Sequence Number: 1 Stage Mean Velocity Gradient(sec^{-1}): 14 Stage Liquid Volume(gal): 924,816		
Sedimentation 1	Surface Area(ft2): 34,012 Liquid Volume(gal): 4,272,067 Baffling type(gal): Average		
Other Treatment	Lime Softening Fluoride Addition	Calcium Hydroxide(CaOH) Hydroflurosilic Acid (F)	2.00 0.90
Sedimentation 2	Surface Area(ft2): 34,336 Liquid Volume(gal): 4,237,749 Baffling type(gal): Average		
Filtration	Surface Area(ft2): 14,560 Liquid Volume(gal): 490,089 Total Media Depth(in): 35 Media type: Sand Minimum water depth to top of Media(ft): 3.3 Depth from top of Media to top of backwash trough(ft): 3.0		

Table 2. Design Plant Engineering Parameters

PWS Name	City of Waco Utility Department
PWS ID	TX1550008
Treatment Plant Name	Mt. Carmel Water Treatment Plant
ICR Treatment Plant ID	639
Treatment Plant Category	Conventional
Water Resource Name	Waco Lake
Water Resource Type	Reservoir/Lake
Average Residence Time(Days)	120
Watershed Control	Yes
State Approved Plant Capacity(MGD)	42.0
Historical Min. Water Temperature(deg C)	5.0
Installed Sludge Handling Capacity (DPD)	0.00
Blending Indicator	No
Hydrologic Unit Code	12060203
River Reach	204
Latitude(degrees, minutes, seconds)	+31°34' 42"
Longitude(degrees, minutes, seconds)	-97° 11'35"
River Reach Miles	4.6

- **Tabular Summary of Source and Finished Water Quality**

Quality of source and conventionally treated finished water during 1998 are shown in Tables 3, and 4.

Table 3. Summary of Source Water Quality

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature(^{0}C)	21.9	5.1	28.5	15
PH	7.7	0.24	8.07	7.3
Turbidity(ntu)	22.8	16.6	62.8	2.8
Alkalinity (mg/L as $CaCO_3$)	121.0	18.1	148	96
Calcium Hardness (mg/L as $CaCO_3$)	143.5	19.4	172	116
TOC(mg/L)	3.22	0.32	3.7	2.8
UV_{254} (cm^{-1})	0.098	0.028	0.131	0.062
Bromide(μg/L)	0.105	0.043	0.19	0.026
TSUVA (L/(mg*m)	3.012	0.967	4.6	1.9

Table 4. Summary of Finished Water Quality

Water Quality Parameters	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature(^{0}C)	21.6	5.5	29	14.7
PH	7.52	0.22	7.88	7.20
Turbidity(ntu)	0.14	0.15	0.2	0.06
TOC(mg/L)	2.86	0.27	3.40	2.50
UV_{254} (cm^{-1})	0.063	0.008	0.075	0.051
DS-THM4(μg/L)	47.45	18.98	74.7	30.6
DS-HAA5(μg/L)	25.58	6.63	32.6	16.6
DS-HAA6(μg/L)	33.53	8.08	42.6	23.0

III. Materials And Methods

♦ Granular Activated Carbon

Granular activated carbon for the RSSCT obtained from Calgon Carbon Corporation was 12 × 40 US std mesh size. This sample was ground using a mortar and pestle and sieved to separate 80 × 120 US size carbon particles. After sieving, the ground carbon was washed with ultra pure water (riverse osmosis) by a stepwise decantation process in order to remove fine carbon particles that could cause pressure build-up during the RSSCT runs. The washed carbon was dried to a constant weight at 100° C and stored in air tight containers in a desiccator.

♦ Chlorination Study

In order to analyze the disinfection byproducts, the GAC RSSCT samples must be chlorinated under site specific simulated distribution system(SDS) conditions. Incubation time, temperature, pH, and chlorine residual should be representative of plant's distribution system conditions at the time of the study.

Total organic content of the GAC effluent increases with time. Chlorine demand also increases throughout the break-through curve. The chlorine dose should be adjusted to the demand of each sample with a goal of obtaining a target of free residual chlorine concentration of 1.0 ± 0.5 mg/L. The Chlorination study was conducted according to the ICR manual for Bench and Pilot study treatment studies . A total of 7 dilution samples were collected. Chlorine dose and chlorine demand that yielded the nearest to the target residual for each dilution were used to generate the plot of chlorine dose against TOC.

Table 5 shows the chlorine dose and the chlorine demand for the 7 dilution samples study parameters, and **Figures 2, 3, 4** were used to determine the chlorine dose for each GAC effluent sample throughout the study.

During the GAC RSSCT study following conditions were used as target SDS conditions to simulate the distribution system.

Incubation time	: 3 hours (1-3 Quarters) 8 hours(4th Quarter)
Incubation temperature	: $21 \pm 10\ ^{0}C$
pH	: 8 ± 0.2

The measured SDS conditions are reported in the data collection spreadsheets.

- **Pretreatment Processes to the GAC Bench Scale Study**

  - **Schematics of the Pretreatment Processes**

The schematic of the pretreatment configuration is shown in **Figure 5.**

- **GAC Influent water- Design data**

The influent water should be free of chlorine in order to measure total organic carbon since Chlorination will interfere with the TOC analysis. At the Mt.Carmel water treatment plant chlorine is added at the beginning of the treatment cycle. In order to get chlorine free water the lake water was collected from the raw water station and pretreated to simulate the water treatment plant by a batch process. Coagulant addition and the mixing procedures were followed as performed in the water treatment plant. Every quarter about 800 liters of GAC influent was prepared with the use of fore 55 gallon plastic drums. Aqualum obtained from the Coastal Products and Chemical Company was used as coagulant. Aqualum is a polymer coagulant with a mixture of Aluminum Sulfate, Poly(Diallyl Dimethyl) Ammonium Chloride, and Copper Sulfate. For each 55 gallons about 0.24 mg/L dose of Aqualum was added and mixed @ 56 rpm for 4 minutes, and @15 rpm for 30 minutes to simulate the SDS fast and slow mix conditions. This treated water was allowed to settle for 12 hours to simulate the primary and secondary sedimentation processes. This settled water was filtered through 10 μm filter to simulate the treatment plant's filtration process.

- **Advanced Treatment Process Information**
  - **Granular Activated Carbon Adsorption Technique Bench Scale Study Using Rapid Small Scale Column Test**

Granular activated carbon adsorption technique is one of the low cost and best available technologies suggested by EPA for natural organic mater removal. In this study a bench-scale model called rapid small scale column test (RSSCT) apparatus was used to determine the effectiveness of GAC in the removal of organic precursors in order to reduce the disinfection by-products in the finished water. This advanced treatment study was conducted at every season as a quarterly study over a period of one year to observe the seasonal variations in water quality and adsorption behavior of the GAC. In addition to seasonal variations two different contact times were used to evaluate the effectiveness of GAC. Also two different SDS incubation times were used throughout the study. **Table 5.** shows the experimental design used in this study.

Table 5

Season	Pre-treatment	EBCT,mintues	SDS incubation time hours
Spring/summer	Conventional filtration	10 ,20	3
Summer	Conventional filtration	10 ,20	3
Autumn	Conventional filtration	10 ,20	3
Winter	Conventional filtration	10 ,20	8

- **Rapid Small Scale Column Test apparatus**

The schematic of the equipment configuration for the RSSCT is shown in

Figure 6. One quarter inch (1/4") Teflon tubing which could withstand appropriate pressures were used throughout the system. Diaphragm metering pumps obtained from Cole Palmer Instrument Company (Model # A142-155) with separate controls for stroke and speed frequencies were used side by side to conduct 10 min and 20 min Empty bed contact time (EBCT) runs. Pressure gauges that would measure 0 to 100 psi were used to monitor the pressures on both systems during the complete run. Two Omnifit high performance glass chromatography columns with Teflon end plates(Altech, part # 51160) of 50 cm long and an inner diameter of 10 mm were used. In order to minimize the chances of channeling in the column the inner diameter of the column should be atleast 25 times greater than the APD of the GAC. In this study the diameter of the columns was selected in such a way that the ratio of column diameter to carbon diameter is 66. Glass columns were used to monitor the GAC filter media throughout the operation.

During each run the RSSCT influent was prefiltered before it enters the column with 1 μm inline cartridge filter. This helped to reduce the excessive pressure build-up during the run.

- **GAC-RSSCT Design Data**

GAC type	:	Bituminous coal based
carbon		
Manufacturer	:	Calgon Carbon Corp,
Pittsburgh		
Original GAC mesh size (US std mesh)	:	12 × 40
RSSCT GAC (US std mesh)	:	80 × 120
Diameter of full-scale GAC, d_{LC} (mm)	:	1.052

$EBCT_{LC}$ = 10 min

RSSCT Carbon particle diameter, d_{SC} (mm)	:	0.15
RSSCT column inner diameter, D_{SC}(mm)	:	10
RSSCT column length, l_{SC}(cm)	:	50
Bed depth, l_{SC}(cm)	:	13.2
$EBCT_{SC}$ (min)	:	1.45
Minimum RSSCT Reynolds number, Re_{SC},min	:	0.5
Full-scale bed porosity, ε_{LC}	:	0.45
Measured RSSCT dry bed density, ρ_{SC}(g/cm^3)	:	0.5
Mass(dry) of GAC, msc (g)	:	5.18
Kinematic viscosity @ T^{0}C, γ_{LC}(m^2/s)	:	1.027E-06
Scaling Factor, SF	:	6.90
RSSCT hydraulic loading rate, v_{SC}(m/hr)	:	5.45
RSSCT flow rate, $_{QSC}$(ml/min)	:	7.07

$EBCT_{LC}$ = 20 min

RSSCT Carbon particle diameter, d_{SC} (mm)	:	0.15
RSSCT column inner diameter, D_{SC}(mm)	:	10
RSSCT column length, l_{SC}(cm)	:	50
Bed depth, l_{SC}(cm)	:	26.3
$EBCT_{SC}$ (min)	:	2.90
Minimum RSSCT Reynolds number, Re_{SC},min	:	0.5
Full-scale bed porosity, ε_{LC}	:	0.45
Measured RSSCT dry bed density, ρ_{SC}(g/cm^3)	:	0.5
Mass(dry) of GAC, msc (g)	:	10.34
Kinematic viscosity @ T^{0}C, γ_{LC}(m^2/s)	:	1.027E-06
Scaling Factor, SF	:	6.90
RSSCT hydraulic loading rate, v_{SC}(m/hr)	:	5.45
RSSCT flow rate, $_{QSC}$(ml/min)	:	7.07

- **Column Packing**

The columns used in the RSSCT were packed with the carbon by slurry packing. Appropriate mass of carbon was weighed and packed as a slurry for 10 and 20 min EBCT runs. The columns were tapped very gently during the addition of GAC slurry to pack the carbon particles as the column was filled.

♦ Experimental Design

The experimental design was based on the design equations used in the ICR manual for bench- and pilot-scale treatment studies. Following are the summary of the design parameters used in all four quarters.

Table 6

First Quarter
RSSCT influent TOC : 3.3 mg/L

No	Parameter	EBCT$_{(10\ min)}$	EBCT$_{(20min)}$
1	d_{LC} (mm)	1.10	1.10
2	d_{SC} (mm)	0.15	0.15
3	SF	6.9	6.90
4	$EBCT_{SC}$ (min)	1.45	2.90
5	v_{SC} (m/h)	5.45	5.45
6	l_{SC} (cm)	13.2	26.3
7	Q_{SC} (ml/min)	7.07	7.07
8	$BV_{50+30\%}$ (bed volume)	5748	5748
9	t_{50} (days)	40	80
10	t_{LC} (days)	80	160
11	t_{SC} (days)	11.6	23.2
12	$V_{SC\ +30\%}$ (L)	154	307
13	GAC mass (g)	5.18	10.34

Table 7

Second Quarter
RSSCT influent TOC : 3.4 mg/L

No	Parameter	EBCT$_{(10\ min)}$	EBCT$_{(20min)}$
1	d_{LC} (mm)	1.05	1.05
2	d_{SC} (mm)	0.15	0.15
3	SF	6.9	6.90
4	$EBCT_{SC}$ (min)	1.45	2.90
5	v_{SC} (m/h)	5.45	5.45
6	l_{SC} (cm)	13.2	26.3
7	Q_{SC} (ml/min)	7.07	7.07
8	$BV_{50+30\%}$ (bed volume)	5837	5837
9	t_{50} (days)	40.5	81
10	t_{LC} (days)	81	162
11	t_{SC} (days)	11.74	23.48
12	$V_{SC\ +30\%}$ (L)	156	310
13	GAC mass (g)	5.18	10.34

Table 8

Third Quarter
RSSCT influent TOC : 3.2 mg/L

No	Parameter	$EBCT_{(10\ min)}$	$EBCT_{(20min)}$
1	d_{LC} (mm)	1.05	1.05
2	d_{SC} (mm)	0.15	0.15
3	SF	6.9	6.90
4	$EBCT_{SC}$ (min)	1.45	2.90
5	v_{SC} (m/h)	5.45	5.45
6	l_{SC} (cm)	13.2	26.3
7	Q_{SC} (ml/min)	7.07	7.07
8	$BV_{50+30\%}$ (bed volume)	6219	6219
9	t_{50} (days)	43	86
10	t_{LC} (days	86	172
11	t_{SC} (days)	12.5	24.9
12	$V_{SC\ +30\%}$ (L)	167	332
13	GAC mass (g)	5.18	10.34

Table 9

Fourth Quarter
RSSCT influent TOC : 3.5 mg/L

No	Parameter	$EBCT_{(10\ min)}$	$EBCT_{(20min)}$
1	d_{LC} (mm)	1.05	1.05
2	d_{SC} (mm)	0.15	0.15
3	SF	6.9	6.90
4	$EBCT_{SC}$ (min)	1.45	2.90
5	v_{SC} (m/h)	5.45	5.45
6	l_{SC} (cm)	13.2	26.3
7	Q_{SC} (ml/min)	7.07	7.07
8	$BV_{50+30\%}$ (bed volume)	5536	5536
9	t_{50} (days)	38.4	77
10	t_{LC} (days)	77	154
11	t_{SC} (days)	11.14	22.28
12	$V_{SC\ +30\%}$ (L)	147	295
13	GAC mass (g)	5.18	10.34

- **Analytical Methods**

The analytical methods and the MRLs used during the treatment study are shown in the following **Table 10**

Analyte	Method	Minimum Reporting Level
Alkalinity	SM 2320-B	2.0mg/L
Ammonia	SM 4500-NH3D	3.0mg/L
Bromide	EPA 300.0	80mg/L
Calcium Hardness	SM 3111-B	30mg/L
Chlorine Residual	SM 4500-Cl F	0.1mg/L
MCAA	EPA 552.2	2.0µg/L
MBAA	EPA 552.2	1.0µg/L
DCAA	EPA 552.2	1.0µg/L
TCAA	EPA 552.2	1.0µg/L
BCAA	EPA 552.2	1.0µg/L
DBAA	EPA 552.2	1.0µg/L
THM4	EPA 524.2	1.0µg/L
Total Hardness	SM 2340-C	30mg/L
TOC	SM 5310-C	0.5mg/L
TOX	SM 5320-B	25.0µg-Cl/L
Turbidity	SM 2130-B	0.01ntu
UV254	SM 5910-B	0.001cm^{1}

Table 11

Laboratories Conducting Analyses During the GAC Treatment Study

Laboratory	Dates of Service	Analyses Performed	ICR Lab ID	Name, Address Phone #
Utility Lab	4/17/98 - 03/04/99	Alkalinity, Calcium hardness, Chlorine residual, pH, Temperature, Total hardness, TOC, UV_{254}, Br	ICRTX007	Jeyanthi Logaraj 2905 Mt. Carmel Dr Waco,TX 76710 PH # (254)751-8554
Environmental Health Lab	4/17/98 - 03/04/99	Ammonia, HAA5, HAA6, THM4, TOX	ICRIN004	Richard Radcliff 110 S. Hill Street South Bend.IN 46617 ph # (219) 233-4777

III. Results And Discussion

- **Problems Encountered**

During the GAC-RSSCT study, for the first three quarters the SDS incubation time used was 3 hours. The reason for using three hours is, at the treatment plant , the travel time from the clearwell to the distribution point is approximately 3 hours. The treated water stays in the clearwell for approximately 5 hours before it goes to the distribution system. For the 4th quarter the incubation or retention time used was 8 hours which is the sum of retention time in the clearwell, and the traveling time. During the study there was no pressure build-up or head loss problem accured. However, during each run the in-line 1µm filter was replaced twice , and the run was stopped for approximately 5 minutes during each filter change.

- **Water Quality Data**

  - **Quality of Pretreated influent water**

Table 12 depicts the quality of pretreated GAC influent water in all four seasons.

Summary average of the pretreated influent water quality

Water quality parameter	Spring Average	Summer Average	Autumn Average	Winter Average
Temperature	22.5	24.15	24.0	21.7
PH	7.94	8.02	7.77	7.71
Turbidity(ntu)	0.485	0.29	0.44	0.16
Alkalinity (mg/L as $CaCO_3$)	133.5	112.5	100.0	119.5
Calcium Hardness (mg/L as $CaCO_3$)	130.5	104.1	92.0	145.7
Total Hardness (mg/L as $CaCO_3$)	164.5	127	114.5	159.5
Bromide(μg/L)	115	136.3	114.2	140.8
TOC(mg/L)	3.16	3.46	3.31	3.34
$UV_{254}(cm^{-1})$	0.059	0.062	0.062	0.056
SDS-THM4(μg/L)	49.39	49.1	41.64	52.0
SDS-HAA5(μg/L)	21.84	20.45	13.85	19.59
SDS-HAA6(μg/L)	28.12	27.84	20.1	27.17
SDS-TOX(μg Cl^-/L)	395.4	159.2	143.2	143.3
SDS- Chlorine Demand(mg/L)	2.95	3.6	2.77	2.19

  - **DBP data and data analysis**

Summary of the GAC effluent water quality during four seasons of the RSSCT study are shown in **Table13**.

Since the effluent water quality of 10 minute and 20 minute runs are almost the same the results of 10 minute EBCT runs are used to determine the impact of seasonal changes on the GAC performance.

Table 13. Summary average of finished water during the experimental run.

Water Quality Parameter	Spring Average	Summer Average	Autumn Average	Winter Average
Temperature	23.0	24.0	22.5	21.0
PH	8.2	7.9	7.89	8.0
SDS-TOC(mg/L)	2.36	2.54	2.59	2.45
SDS-UV(cm^{-1})	0.036	0.033	0.033	0.025
SDS-THM4(mg/L)	40.70	38.75	29.75	37.60
SDS-HAA5(mg/L)	9.75	9.0	8.3	9.65
SDS-HAA6(mg/L)	14.15	13.3	12.0	14.25
SDS-Chlorine Demand(mg/L)	211	2.6	2.15	1.34
SDS-Incubation time(Hours)	3	3	3	8

Following are the breakthrough curves that are constructed by plotting concentrations of various water quality parameters as a function of operating times. (***10 figures-SDS-THM4-10min,20min,SDS- TOC-10min,20min,SDS-TOX10min,20min,SDS-HAA5,SDS-HAA610min,20min)***

1. At low TOC levels, the dominant byproduct was dibromochloromethane.

2. There is more brominated THMs at lower TOC concentrations.

3. Also at higher bromide concentrations there is more brominated THMs.

4. All four tests show, for the same TOC concentration, with different bromide levels, the THM formation increased with the increase in bromide concentration.

Table 14 depicts the different times to reach various Breakthrough criteria and the water quality of GAC effluent when those criteria are met.

Table -14 Times to reach Breakthrough Criteria for SDS-THM4 and the water quality of GAC effluent when those criteria are met.

Breakthrough Criterian	Run Time (hours)	Bed Volume	TOC (mg/L)	SDS-THM4 (μg/L)	SDS-TOX (μg/L)	SDS-HAA5 (μg/L)	SDS-HAA6 (μg/L)
SDS-THM4 =39.6(μg/L)	578.00	11967.4	2.2	39.6	180	7.60	11.00
SDS-THM4 =20.40(μg/L)	334.50	6925.8	1.54	20.40	71.25	3.95	6.15
SDS-THM4 =10.10(μg/L)	238.0	4927.8	1.26	10.10	44.00	2.20	3.50

In all four runs the SDS- HAA5 concentration in the GAC effluent is less than the required amount of 30 (μg/L) in order to meet the stage 2 DBP rule.

- **Impact of Seasonal Variation**

The data used to determine the impact of seasonal variation on the source water quality and the finished water(by conventional treatment) during 1998 are taken from the 18 month ICR monitoring. The seasonal average of the parameters to evaluate the GAC performance are shown in the following tables.

Table -15 Raw water Quality -1998

Water Quality Parameters	Spring Average	Summer Average	Autumn Average	Winter Average
Temperature 0C	24.3	27.7	19.8	15.7
PH	7.88	7.69	7.62	7.62
Turbidity (ntu)	13.9	18.51	17.0	41.96
TOC (mg/L)	3.17	3.23	2.87	3.6
UV254 (cm^{-1})	0.079	0.065	0.124	0.118

Table 16 Finished Water Quality-1998

Water Quality Parameters	Spring Average	Summer Average	Autumn Average	Winter Average
Temperature 0C	24.3	28.1	19.1	15.1
PH	7.5	7.29	7.53	7.75
Turbidity (ntu)	0.07	0.14	0.13	0.18
TOC (mg/L)	3.0	2.93	2.53	2.97
UV254 (cm^{-1})	0.063	0.053	0.067	0.07
THM4 (μg/L)	74.7	42.6	30.6	41.9
HAA5 (μg/L)	32.6	26.6	16.6	26.5
HAA6 (μg/L)	42.6	35.1	23.0	33.4

The seasonal variation dose not have much impact on the raw water quality. The raw water quality is more or lass same during all seasons. Even though there is a slight variation in the organic precursors, the maximum disinfection by product is produced during spring season. Conventional treatment is not effective in the removal of natural organic carbon in the water. During spring season the trihalomethane produced is almost close to the stage I DBP requirement of 80 μg/L. In order to meet the stage II DBP rule another advanced treatment technique along with the conventional pretreatment should be required.

- **Cost Analysis**

The amount of GAC required for Mt. Carmel water treatment plant was determined from the design information

Design basis:

Flow:	7800 MGD = 21.5 MGD = 14,930 GPM
Filters:	16 Filters, 26' Wide × 35' Long
Area:	910 ft^2 / Filter
Total Area :	14,560 ft^2

Calculations:

Superficial velocity = 14,930 GPM/ 14,560 ft^2
Based on an estimation from Calgon Carbon Corporation,
Depth of GAC needed for $EBCT_{10}$ = 16"
Depth of GAC needed for $EBCT_{20}$ = 33"

Mass of GAC based on 28.5 LB/ ft^3

For $EBCT_{10}$ 34,580 LB/ Filter or 553,300 LB Total

For $EBCT_{20}$ 71,320 LB/ Filter or 1,141,100 LB Total

Comments:

1. The calculation assumes that all filters are utilized. If all filters are not used, the depth of GAC would have to increase proportionally to maintain the contact time.

2. If all the filters are not utilized, the total amount of GAC increases because all the filters must have sufficient depth to maintain the contact time.

3. The current filter design can contain the bed of GAC for the case of $EBCT_{10,}$ which is 16”. For $EBCT_{20}$ the filters would need to be rebuilt. From the top of the gravel there should be minimum 6” sand, 33” GAC, and 17” of freeboard for expansion, for a total of 56”. Currently there is 39” from the gravel to the bottom of the trough.

The scope of the filter renovation should be thoroughly investigated for the most cost effective solution. Replacing the underdrain may be less expensive than raising the troughs.

4. Eventhough the bench scale study shows $EBCT_{10}$ will work as good as the $EBCT_{20}$, in the full scale treatment, $EBCT_{20}$ will be more effective and economical than the 10 minute EBCT. The reason is, in the 20 minute EBCT GAC bed, the carbon depth will be more so will the mass transfer zone , compare to the 10 minute bed depth. This will increase the adsorption comparatively. Also theoretically for 20 minute contact time, GAC will be replaced every six months instead of every three months. In practical carbon can be replaced once a year due to the biological activity. This would reduce half of the carbon handling cost. In the beginning the expense would be a lot, but in the long run the city can save lot of money.

5. Another way to save money is to replace the carbon, few filters at a time, and blend the effluent from the fresh GAC bed with the effluent from the other GAC beds.

6. The cost of the GAC to convert the filters could be estimated to be $0.60/ LB of GAC. For $EBCT_{10}$ the cost would be $332,000. For $EBCT_{20}$ the cost would be $664,000. This dose not include the cost to renovate the filters.

Cost Estimation from the RSSCT Study:

Since the study was mainly to investigate the performance of GAC to meet the DBP stage 2 rule, the breakthrough point used in the calculation was 40 μg/L. From 10 minute EBCT runs, the average number of hours to reach the breakthrough were 415. The carbon usage rate was 5.2g / 415 hr to treat 46 gallons water. The average volume of water treated at Mt. Carmel plant is 22 MGD. Carbon required to treat 7800 MGY is 1935310 lb. The cost of carbon/LB is estimated to be $.60. The cost of GAC to treat 1000 Gallons will be approximately 0.15$. Without considering biological activity in the GAC, 553,300 LB of carbon will last for 3 months. With biological activity carbon may last for a year.

Since there is one time, cost for installing GAC, the city should consider alternate options, such as installation of GAC on a service basis. This option will distribute the cost over a several year time period

- **Summary of Results**

The study shows during all four seasons, there was not much variation in the raw water quality. In the finished water trihalomethane concentration was higher during the spring season , as expected due to the stratification. GAC adsorption technique worked well in the removal of organic carbon content in the water. As a result, the disinfection by product formation have been reduced in all four seasons which will be in compliance with the DBP stage II regulations. GAC adsorption seems to be a cost effective technology among the available technology to meet the present and future drinking water regulations for the city of Waco.

III. QA/QC Summary

The RSSCT bench scale study shows, $EBCT_{10}$ work the same way as $EBCT_{20.}$ The difference between the MTZ (mass transfer zone) in 10 minute contact time and 20 minute contact time seems to be very low in the range of <5%. In full scale GAC bed, since the bed is used for a much longer periods compared to the bench scale study there would be some biological activity. Because of this and also since the 20 minute GAC bed is used for longer periods compared to the 10 minute GAC bed, the 20 minute bed life will be more than double that of 10 minute bed life.

Times to reach breakthrough criteria for SDS-THM4 and the water quality of GAC effluent when those criteria are met for $EBCT_{10}$

Breakthrough Criterian	Run Time (hours)	Bed Volume	TOC (mg/L)	SDS-TOX (mg/L)	SDS-THM4 (µg/L)	SDS-HAA5 (µg/L)	SDS-HAA6 (µg/L)
SDS-THM4 = 37.7(µg/L)	415.0	17186	2.5	125.85	37.7	9.09	13.44
SDS-THM4 = 20.98(µg/L)	162.7	6736	1.73	51.84	20.98	5.7	8.50
SDS-THM4 = 10.19(µg/L)	103.7	4292	1.30	43.75	10.19	2.66	4.12

Times to reach breakthrough criteria for SDS-THM4 and the water quality of GAC effluent when those criteria are met for $EBCT_{20}$

Breakthrough Criterian	Run Time (hours)	Bed Volume	TOC (mg/L)	SDS-TOX (mg/L)	SDS-THM4 (µg/L)	SDS-HAA5 (µg/L)	SDS-HAA6 (µg/L)
SDS-THM4 = 37.24(µg/L)	682.4	14129	2.44	106.8	37.24	8.75	12.74
SDS-THM4	381.6	7902	1.74	46.94	20.0	3.76	5.81

= 20.0(μg/L)							
SDS-THM4 = 9.4(μg/L)	244.3	5057	1.3	35	9.4	2.08	3.03

Bromide-EPA 300.0

Scalar Autosampler:

Calibration Procedure:

1. Following calibration standards were prepared from the custom standard.

   0.250 ppm
   0. 5 ppm
   1.0 ppm
   2.0 ppm
   4.0 ppm

2. Load each standard in five individual vials and place them in the Autosampler.

3. Prepare a schedule for calibration as Autocal 1, Autocal 2, Autocal 3, Autocal 4, and Autocal 5.

4. Go to Load Schedule. Bring up the prepared schedule.

5. Hit Run. Then start the analysis.

Frequency of calibration check was conducted as mentioned in the DBP/ICR Analytical methods manual. Ref., page 49., table 9.1

Total Organic Carbon - SM 5310 C

TOC Analyzer- Persulfate Oxidation Method:

Calibration Procedure:

Prepare calibration standards in the following concentrations.

Std 1 DI blank

Std 2 0.5 ppm

Std 3 1.0 ppm

Std 4. 5.0 ppm

Std 5. 10.0 ppm

1. Prepare Potassium Biphthalate Stock solution(KHP)(1000 ppm C) by adding 2.128 g of KHP into a 1000 ml volumetric flask. Dilute to volume with reagent water. Calibration standards are prepared using this stock solution.
2. Fill the 40 ml vials with the calibration standards, and load them in the TOC Analyzer's Autosampler.
3. Press F4 to bring up the Sequence screen.
4. Press 2 to select Std.
5. Enter number of replicas. (which is in our procedure 2)
6. Press F1 to start the calibration standard analysis.

Calibration and verification check , and the frequency were performed according to the QA/QC procedure described in the DBP/ICR Analytical manual. Ref.: page 49-52 , tables 9.1- 9.4

Disinfection By-Products

Trihalomethanes (THMs) - EPA 524.2

(Environmental Health Lab)

Calibration and verification check , and the frequency were performed according to the QA/QC procedure described in the DBP/ICR Analytical manual. Ref.: page 49-52 , tables 9.1- 9.4

Total Organic Halogens (TOX)- SM 5320 B

(Environmental Health Lab)

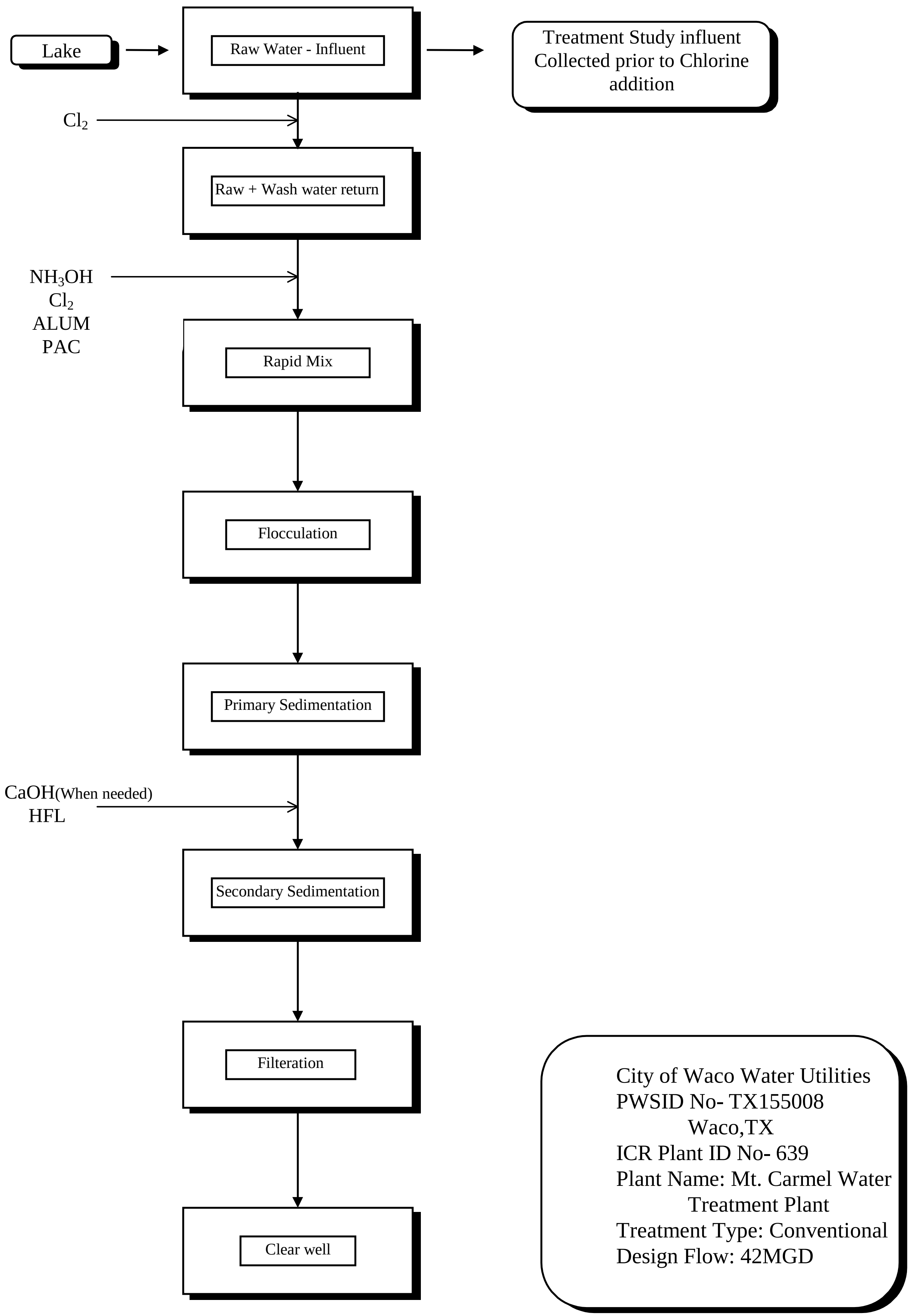
Calibration and verification check , and the frequency were performed according t QA/QC procedure described in the DBP/ICR Analytical manual. Ref.: page 49-52 , tables 9.1- 9.4

Halo Acetic Acid (HAA5, HAA6) - EPA 552.2

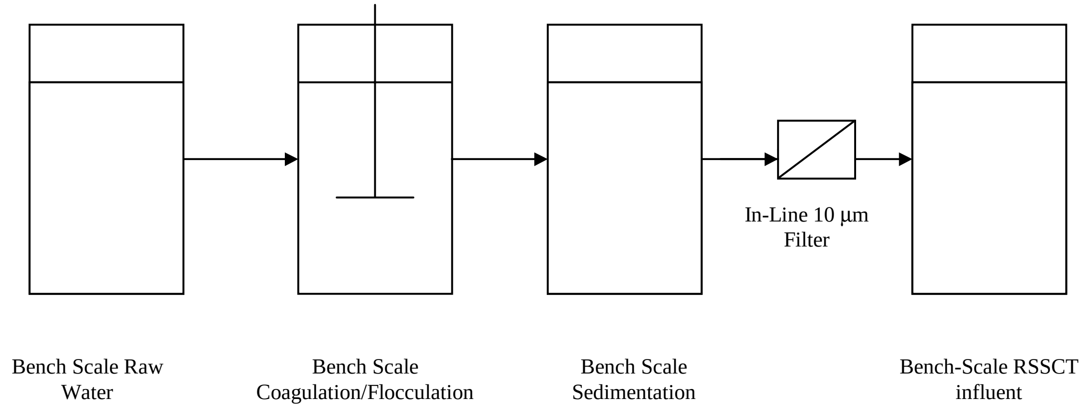
(Environmental Health Lab)

Calibration and verification check , and the frequency were performed according to the QA/QC procedure described in the DBP/ICR Analytical manual. Ref.: page 49-52 , tables 9.1- 9.4

Figures



Schematic of the Full Scale Treatment Plant, Fig. 1



Schematic of the Bench-Scale Pretreatment System Used Prior to RSSCT Bench -Scale GAC Study

Figure-5

Rapid Small Scale Column Test Apparatus

10 Minute RSSCT Run | **20 Minute RSSCT Run**

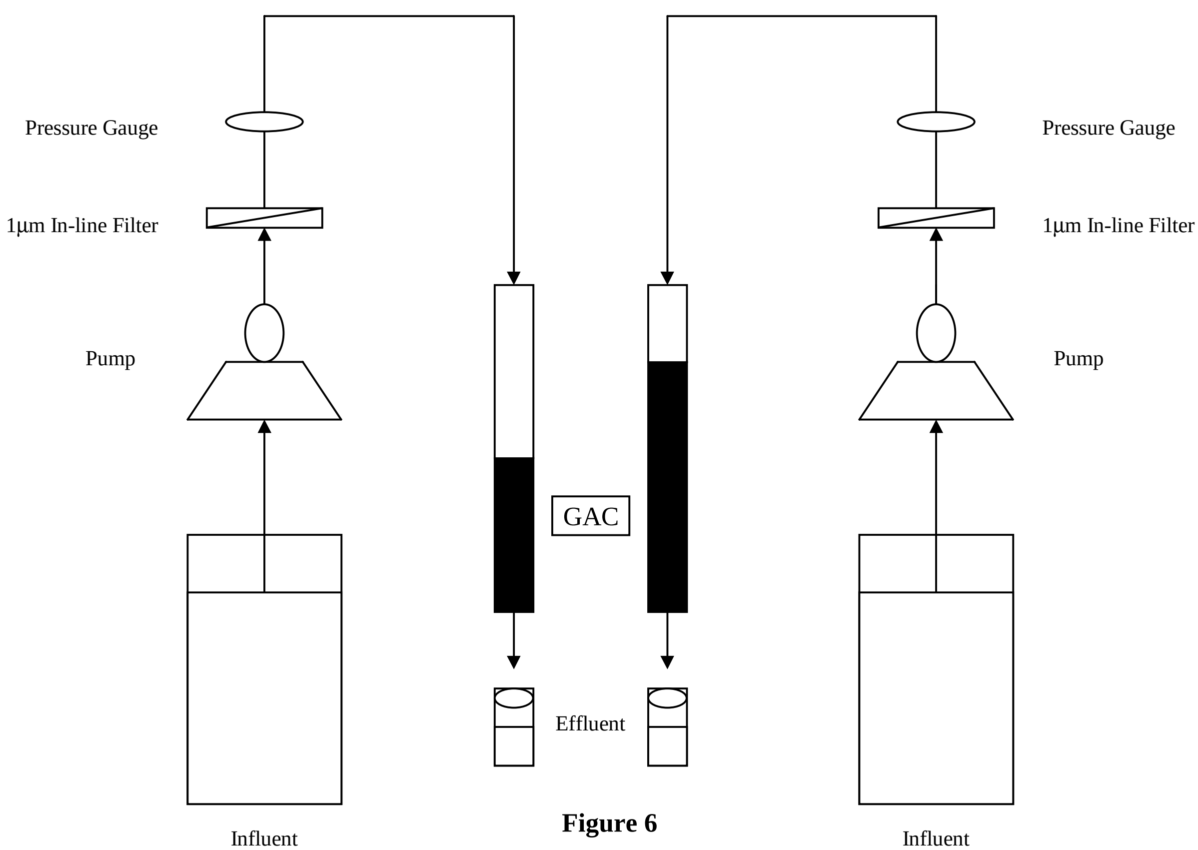


Figure 6