“THROW THE KITCHEN SINK AT IT!” POWDERED ACTIVATED CARBON OPTIMIZATION FOR TASTE AND ODOR REMOVAL IN DRINKING WATER

Authors:

Rachel Monschein, Chemist/Laboratory Supervisor
Town of Cary

Erin Lee, Senior Laboratory Analyst
Town of Cary

Cary/Apex Water Treatment Facility
1400 Wimberly Rd.
Apex, NC 27523

April 28, 2017

AUTHOR INFORMATION PAGE

Powdered Activated Carbon Optimization for Taste and Odor Removal in Drinking Water

Rachel Monschein
Chemist/Laboratory Supervisor
Cary/Apex Water Treatment Facility
1400 Wimberly Rd.
Apex, NC 27523
919-362-5507
rachel.monschein@townofcary.org

Rachel Monschein has been the Chemist/Laboratory Supervisor for the Cary/Apex Water Treatment Facility in Apex NC since January 2014. Prior to that she worked for Orange Water and Sewer Authority's Water Treatment Plant's laboratory in Carrboro NC for 18 ½. She has a Bachelor's of Arts Degree in Environmental Studies with honors in Biology from the University of North Carolina at Wilmington. She published an honors thesis from the University of North Carolina at Wilmington entitled, Macroalgal Biomass and Species Composition as Indicators of Nutrient Loading in Two North Carolina Tidal Creeks, in May of 1995.

She has her Process Control Chemistry Certification, Total and Fecal Coliform Certification, A-Surface Water Treatment Facility Operator license, Cross-Connection Control System Operator license, A-Distribution Water Operator's license, C-Well Water Operator's license, Grade I Biological Wastewater Operator's license, and a Grade I Physical Chemical Wastewater Operator's license.

Erin Lee
Senior Laboratory Analyst
Cary/Apex Water Treatment Facility
1400 Wimberly Rd.
Apex, NC 27523
919-362-5502
erin.lee@townofcary.org

Erin Lee has been employed by the Cary/Apex Water Treatment Facility since October 2005. She has a Bachelor of Science degree in Forensic Science from Eastern Kentucky University. Prior to that she worked as a Water Plant Operator for the Town of Pittsboro (from August 2004 – October 2005). She has her Process Control Chemistry certification, Total Fecal Coliform certification, A-Surface Water Treatment Facility Operator license, and a Grade I Physical Chemical Water Pollution Control System Operator license.

"THROW THE KITCHEN SINK AT IT!" POWDERED ACTIVATED CARBON OPTIMIZATION FOR TASTE AND ODOR REMOVAL IN DRINKING WATER

Rachel Monschein, Chemist/Laboratory Supervisor, Town of Cary
Erin Lee, Senior Laboratory Analyst, Town of Cary

ABSTRACT

Malodorous compounds in drinking water negatively impact the consumer's confidence in the safety of their drinking water. An important part of the job of water treatment personnel is to not only produce drinking water that is safe to drink but to also produce water that is aesthetically pleasing.

Powdered activated carbon (PAC) is utilized by the Cary/Apex Water Treatment Facility in Apex, NC to mitigate the tastes and odors caused by algal metabolites in the source water, Jordan Lake. Geosmin (trans-1, 10-dimethyl-trans-9-decalol) and MIB (2-methylisoborneol) are compounds released by some algae that cause earthy musty odors. These compounds are not harmful to people but the taste and odors can be quite noticeable for those with sensitive noses and palates.

In the past the water treatment facility's only option was to "Throw the kitchen sink at it!" - Or feed the maximum amount of PAC possible. The goal of this project was to find the level at which PAC is effective at reducing the MIB and geosmin to levels that can't be detected ascetically while reducing the amount that is overfed.

This project involved several different jar tests analyzing different doses of PAC in lake water (raw water) with varying concentrations of MIB and geosmin in order to determine the optimal dose rate for reducing the metabolites to less than 5 ng/L (below the detectable level for most humans). Feeding more PAC than necessary increases the chemical costs, plus increases the quantity of solids that have to be removed from the solids handling process and wasted. Therefore, finding the level at which PAC is effective at reducing the MIB and geosmin to levels that can't be detected ascetically while reducing the amount that is over fed is important for optimal performance of the treatment facility.

Jar tests were performed on thirteen different dates from December 13th, 2016 through February 16th, 2017. The raw water was spiked with a known quantity of MIB and geosmin (10 ng/L, 200 ng/L or 400 ng/L). Powdered activated carbon was added to each jar in varying quantities. Optimal doses of PAC were determined for each level of MIB and geosmin. The data was graphed, logarithmic curves and equations of the lines were determined. Then two tables (one for MIB and one for geosmin) were generated so that optimal PAC dosing could be determined quickly by treatment facility staff.

DESCRIPTION OF OUR WATER TREATMENT PROCESS

The Town of Cary produces drinking water at a treatment plant that it owns with the Town of Apex. The treatment capacity is 40 million gallons per day but a project is currently underway to expand the facility to a capacity of 56 MGD. PAC is typically added at the raw water pump station located on Jordan Lake. Then the water is pumped 6 miles to the water plant. Additional PAC can be added as the raw water enters the plant. Ozone is normally used to disinfect, remove organics, and control taste and odor. Then aluminum sulfate (the primary coagulant) is added in the flash mix. Polymer is added as the water enters the SuperPulsators. Water is pulsed up from the bottom, the floc collects on the baffles and the clean water goes out through the collection channels at the top. As water flows to the filters, chlorine in the form of liquid bleach is added for initial disinfection. Water then flows down through layers of sand and anthracite coal in the filters, where additional particles are removed from the water.

After filtration, hydrofluorosilicic acid (fluoride) is added for dental health, pH is adjusted with caustic, and a blend of phosphates is added as a corrosion inhibitor. The water then flows to “clearwells” for temporary storage. µ(Ammonia) is added to the water which combines with the chlorine to form “chloramines” to further disinfect the water (except each March when ammonia is suspended). The drinking water is then pumped to several elevated storage tanks and into more than 1,000 miles of water lines where it serves over 233,000 people in Cary, Morrisville, Research Triangle Park, Raleigh-Durham Airport, and Apex.

The solids from the bottom of the SuperPulsator basins and waste from the filter backwash water is processed to remove solids and chlorine. Then it is discharged to the nearby creek. A centrifuge removes excess water from the wastewater and the alum sludge is shipped in trucks to a local company where it is integrated into nutrient rich compost.

HISTORY OF POWDERED ACTIVATED CARBON USE

Depending on the water quality in Jordan Lake, powdered activated carbon dosages vary from year to year. Since 2010, dosages have ranged from as little as 0 mg/L to as much as 85 mg/L. See Table below for details.

Table 1: *Powdered activated carbon dose ranges by year*

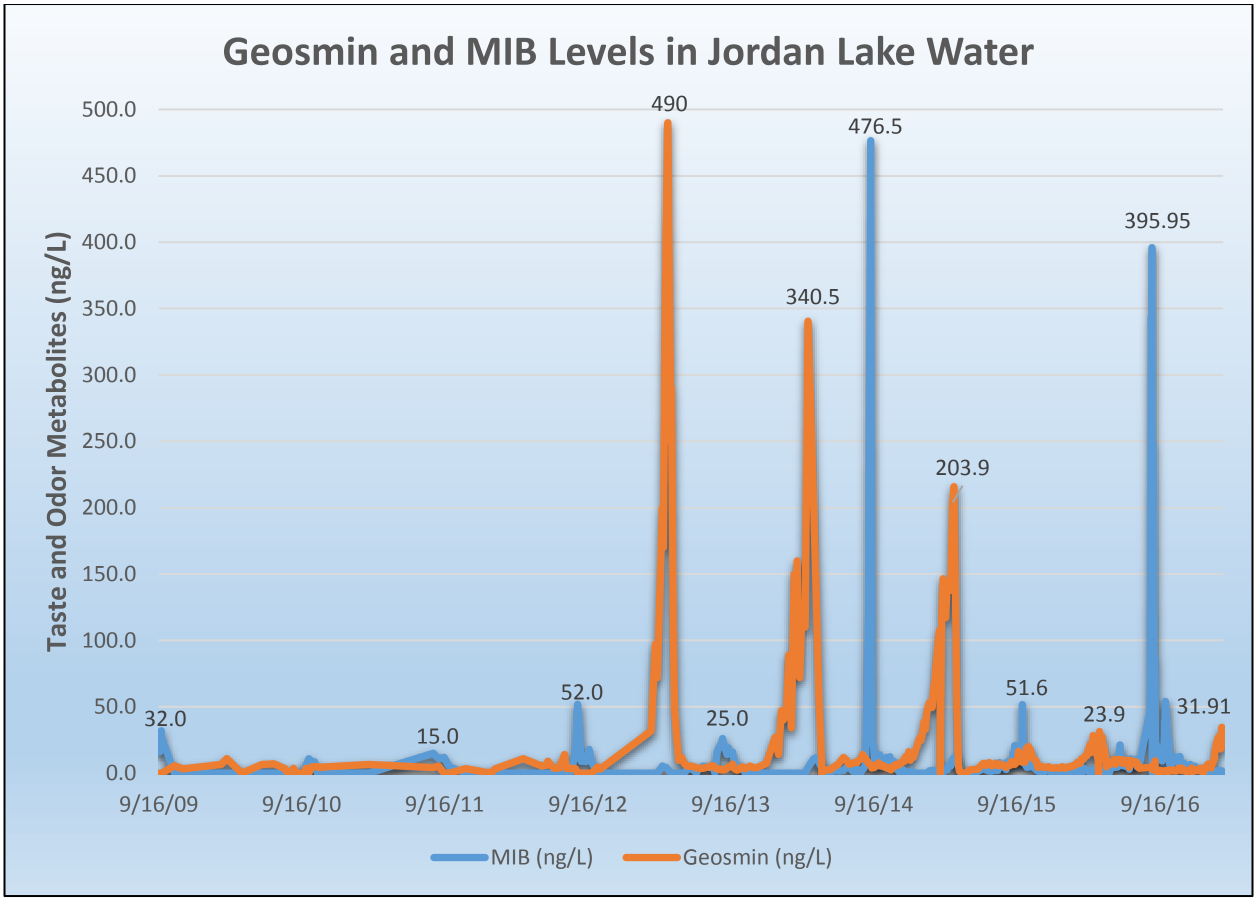
Year	PAC Dose Range (mg/L)
2010	0-32
2011	5-22
2012	4-23
2013	5-38
2014	4-44
2015	5-45
2016	10-85

Powdered activated carbon has become a large portion of the annual water plant chemical budget. Water quality in Jordan Lake has required more PAC in recent years. In 2010, the water treatment facility only budgeted $228,873 or 13% of the chemical budget for water treatment chemicals including alum, caustic, coagulant aid polymer, filter aid polymer, hypochlorite, corrosion inhibitor, carbon, fluoride, ammonia and oxygen. That has steadily increased until in 2017 when $1,216,745 was budgeted for PAC or 46% of the overall chemical budget

HISTORY OF MIB AND GEOSMIN CONCENTRATIONS

Geosmin and MIB are problematic in Jordan Lake at different times of the year. Geosmin tends to increase between January and May whereas MIB spikes in September annually. Monitoring results are only available since September 2009. Geosmin has been measured as high as 490 ng/L, and MIB has been measured as high as 477 ng/L. See chart below for specifics.

Figure 1: *Historical levels of geosmin and MIB in Jordan Lake water*



DESCRIPTION OF THE JAR TEST PROCEDURES

Jar tests were performed on thirteen different dates from December 13th, 2016 through February 16th, 2017. A jar test is a laboratory procedure that simulates a water treatment plant's treatment process. Up to six 2-L beakers (per apparatus) are filled with lake water. A device with six metal paddles is positioned over the beakers to stir the water in each beaker simultaneously. Chemical doses, mix speeds and settling times can be altered in each beaker (jar) to optimize treatment.

Test solutions were prepared for the jar test procedure using samples of the chemicals used in the full scale facility following the Water Treatment Plant Operation, Volume I Sacramento State Training Manual method. A 10,000 mg/L carbon slurry solution of adding 10 grams Standard Purification – Watercarb-800 carbon to 1 liter deionized water. A 2,000,000 ng/L solution of MIB/Geosmin was prepared by adding 0.1 milliliter of the 100µg/mL standard to 4.9 milliliters of methanol. A 10,000 mg/L solution of aluminum sulfate was prepared by adding 15.6 milliliters of liquid alum to a 1 liter of deionized water. A 2,000 mg/L solution of polymer was prepared by adding 1 gram of dry polymer to a beaker containing 500 milliliters of warm deionized water.

In this study, the raw water was spiked with a known quantity of MIB and geosmin (10 ng/L, 200 ng/L or 400 ng/L). Powdered activated carbon was added to each jar in varying quantities. Jars were mixed on slow speed or 28 RPMs for 2.5 hours to simulate the contact time from the intake to the treatment plant.

Carbon was again added (in most cases) to simulate the in-plant addition of powdered activated carbon. Each jar was also dosed with 60 ppm of alum (1µmLs were added to each 2L jar) and 0.2 ppm of polymer (or 0.2 mLs) and then mixed at high speed (100 RPMs) for 30 seconds. Then the jars were ramped down to 25 RPMs and for 25 minutes. They were allowed to settle for 3 minutes. Then samples were filtered with 2µm PTFE filter syringe plungers.

Samples were analyzed using a method that was derived from “Analysis of Odor Compounds in Water by Stir Bar Sorptive Extraction (SBSE)” written by Jack Stuff from GERSTEL Analytical Solutions in 2016. Typically, this method involves adding 2,4,6-Trichloroanisole (TCA) as an internal standard. However, a calibration curve without the internal standard had to be used because it interfered with the analysis.

A GERSTEL Twister stir bar with polydimethylsiloxane (PDMS) sorbent phase (size: 10 mm x 0.5 mm) was added to each 40 milliliter sample and stirred on a stir plate for 2 hours. The Twisters absorbed and concentrated the compounds into their sorbent coating. After extraction, the Twisters were removed from the sample vials with a magnetic rod, rinsed with deionized water and dried with a lab wipe. They were put into empty thermal desorption unit tubes and placed into the Gerstel multipurpose sampler autosampler VT-98t rack. The analytes were desorbed from the Twister using thermal desorption in the splitless mode at 280°C for 3 minutes under a 50 ml/min helium flow.

Next MIB and geosmin concentrations were determined by Gas Chromatograph / Mass Spectrometer (GC/MS) analysis using an Agilent 5890B Gas Chromatograph and 5977B Inert Plus Mass Selective Detector Turbo EI. Analytes were trapped in the cooled injection system (CIS 4) inlet at 10°C on a Tenax-TA liner. Analytes were vaporized and transferred to the Rxi-5 MS (Restek 30 m x 0.25 mm x 0.25 µm) column, in the splitless mode by heating the inlet rapidly to 280°C. The column separates the analytes by solubility and boiling points and sends them individually to the Mass Spec. Analytes are identified based on their retention time. MIB has an approximate retention time of 9.84 min and geosmin has an approximate retention time of 13.69 min. Chromatograms were quantitated to calculate concentrations. The results of all thirteen jar tests are detailed below.

TEST RESULTS

In Jar Test 1, the raw water was spiked with approximately 400 ng/L of MIB and geosmin. 4 mL of the prepared standard was added to a full five gallon bucket (approximately 20 liters) of raw water to obtain approximately 400 ng/L spike. Then the following intake doses were added to each jar: no carbon (control), 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, 60 mg/L, and 70 mg/L (or 0, 2, 4, 6, 8, 10, 12, 14 mLs of the carbon slurry were added to each 2L jar). No PAC was added at the treatment plant. 100% reduction of geosmin was obtained when 60 mg/L of PAC was added at the intake. 100% reduction of MIB was not obtained at the highest dose of 70 mg/L PAC.

In Jar Test 2, the raw water was again spiked with approximately 400 ng/L of MIB and geosmin. Then 30 mg/L of carbon was added at the intake and the in-plant dose of PAC was varied. Plant doses of PAC included the following: 0 mg/L, 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L, 25 mg/L, 30 mg/L and 35 mg/L. 100% reduction of geosmin was obtained when 30 mg/L of PAC was added at the intake combined with 35 mg/L at the treatment plant. 100% reduction of MIB was not obtained at the highest dose of 30 mg/L of PAC intake dose combined with the 35 mg/L dose at the treatment plant.

In Jar Test 3, the raw water was again spiked with approximately 400 ng/L of MIB and geosmin. 40 mg/L was added as the intake dose to 8 of the 9 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, 60 mg/L, and 70 mg/L. 100% reduction of geosmin was obtained when 40 mg/L of PAC was added at the intake combined with 30 mg/L plant PAC dose. 100% reduction of MIB was not obtained at the highest dose of 40 mg/L PAC intake dose and 70 mg/L treatment plant dose.

In Jar Test 4, the raw water was spiked with approximately 200 ng/L of MIB and geosmin. 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, 60 mg/L and 70 mg/L PAC was added as the intake dose to 8 of the 9 jars. No PAC doses were added as the treatment plant. 100% reduction of geosmin and MIB was not obtained at the highest dose of 70 mg/L PAC intake dose.

In Jar Test 5, the raw water was again spiked with approximately 200 ng/L of MIB and geosmin. 40 mg/L was added as the intake dose to 8 of the 9 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, 60 mg/L, and 70 mg/L. 100% reduction of geosmin was obtained when 40 mg/L of PAC was added at the intake combined with 10 mg/L plant PAC dose. 100% reduction of MIB was not obtained at the highest dose of 40 mg/L PAC intake dose and 70 mg/L treatment plant dose.

In Jar Test 6, the raw water was spiked with approximately 10 ng/L of MIB and geosmin. The following PAC doses were added as the intake dose: 0 mg/L, 5 mg/L, 10 mg/L, 15 mg/L, and 20 mg/L. No PAC was added as the treatment plant PAC dose. 100% reduction of geosmin was obtained when 15 mg/L of PAC was added at the intake. 100% reduction of MIB was not obtained at the highest dose of 20 mg/L PAC intake dose.

In Jar Test 7, the raw water was again spiked with approximately 10 ng/L of MIB and geosmin. 20 mg/L was added as the intake dose to 5 of the 6 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 5 mg/L, 10 mg/L, 15 mg/L, and 20 mg/L. 100% reduction of geosmin and MIB was obtained when 20 mg/L of PAC was added at the intake and 0 mg/L plant PAC dose.

In Jar Test 8, the raw water was again spiked with approximately 400 ng/L of MIB and geosmin. 50 mg/L was added as the intake dose to 7 of the 8 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, and 60 mg/L. 100% reduction of geosmin was obtained when 50 mg/L of PAC was added at the intake combined with 20 mg/L plant PAC dose. 100% reduction of MIB was obtained when 50 mg/L PAC was added at the intake combined with 60 mg/L treatment plant dose.

In Jar Test 9, the raw water was again spiked with approximately 400 ng/L of MIB and geosmin. 60 mg/L was added as the intake dose to 6 of the 7 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, and 50 mg/L. 100% reduction of geosmin was obtained when 60 mg/L of PAC was added at the intake combined with 20 mg/L plant PAC dose. 100% reduction of MIB was not obtained at the highest dose when 60 mg/L PAC was added at the intake combined with 50 mg/L treatment plant dose.

In Jar Test 10, the raw water was again spiked with approximately 400 ng/L of MIB and geosmin. 70 mg/L was added as the intake dose to 5 of the 6 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, and 40 mg/L. 100% reduction of geosmin was obtained when 70 mg/L of PAC was added at the intake combined with 10 mg/L plant PAC dose. 100% reduction of MIB was not obtained at the highest dose of 70 mg/L PAC intake dose combined with 40 mg/L treatment plant dose.

In Jar Test 11, the raw water was spiked with approximately 200 ng/L of MIB and geosmin. Intake PAC doses included: 0 mg/L, 40 mg/L, and 50 mg/L to the 7 remaining jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 5 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L, and 60 mg/L. 100% reduction of geosmin was obtained when

50 mg/L of PAC was added at the intake combined with 10 mg/L plant PAC dose. 100% reduction of MIB was not obtained at the highest dose when 50 mg/L PAC was added at the intake combined with 60 mg/L treatment plant dose.

In Jar Test 12, the raw water was again spiked with approximately 200 ng/L of MIB and geosmin. 60 mg/L was added as the intake dose to 6 of the 7 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, and 50 mg/L. 100% reduction of geosmin was obtained when 60 mg/L of PAC was added at the intake combined with 10 mg/L plant PAC dose. 100% reduction of MIB was obtained when 60 mg/L PAC was added at the intake combined with 50 mg/L treatment plant dose.

In Jar Test 13, the raw water was again spiked with approximately 200 ng/L of MIB and geosmin. 70 mg/L was added as the intake dose to 5 of the 6 jars. Then after the 2.5 hour detention time, the following PAC doses were added as the treatment plant PAC dose to each jar: 0 mg/L, 0 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, and 40 mg/L. 100% reduction of geosmin was obtained when 70 mg/L of PAC was added at the intake combined with 0 mg/L plant PAC dose. 100% reduction of MIB was obtained when 70 mg/L PAC was added at the intake combined with 40 mg/L treatment plant dose.

CONCLUSIONS

The data generated from the 13 jar tests was used to determine the ideal dose rates for PAC to reduce the MIB and Geosmin down to 5 ng/L (below the detectable level for most humans).

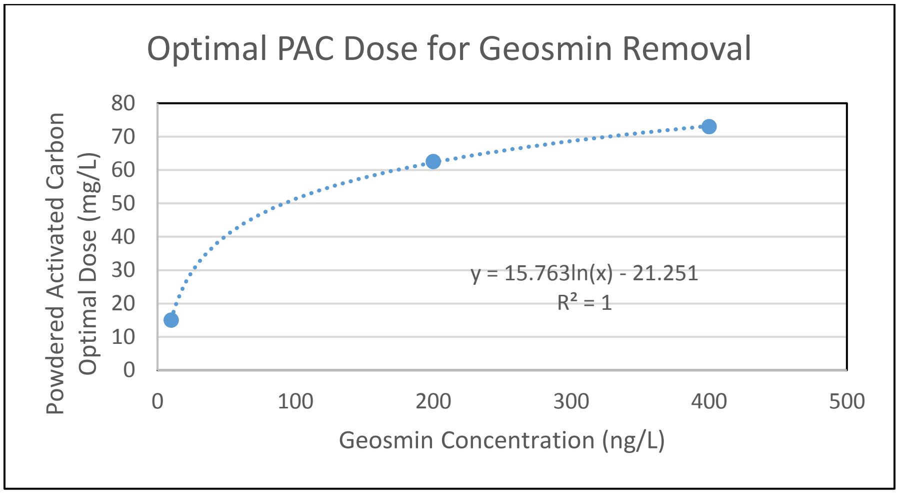
Two of the jar tests obtained 100% reduction of geosmin at the 10 ng/L concentration of geosmin. The optimal dose (combination of intake and plant dose) determined was 15 mg/L of PAC. Several jar tests obtained 100% reduction of geosmin at the 200 ng/L level. Options included 50 mg/L, 70 mg/L, 60 mg/L and 70 mg/L. An average of 62.5 mg/L was calculated as the optimal combined PAC dose. Additionally, several jar tests obtained 100% reduction in geosmin at the 400 ng/L level. They included 65 mg/L, 70 mg/L, 70 mg/L, 80 mg/L and 80 mg/L with an average optimal combined PAC dose of 73 mg/L.

The average combined optimal dose rates for achieving 100% reduction in geosmin were compiled in a table based on the concentration of geosmin used. The points were plotted on a graph with powdered activated carbon optimal dose in mg/L on the y-axis and geosmin concentration (ng/L) on the x-axis. A logarithmic trend line was added and the equation of the line was calculated: $y = 15.763 \ln(x) - 21.251$, where the PAC dose = y and x = geosmin concentration. The correlation coefficient or R-squared value was 1.

Table 2: *Optimal PAC Dosages for Geosmin Removal*

Optimal PAC Dose for Geosmin Removal	
Geosmin (ng/L)	Average Optimal PAC Dose (mg/L)
10	15
200	62.5
400	73

Figure 2: *Optimal PAC Dose for Geosmin Removal*



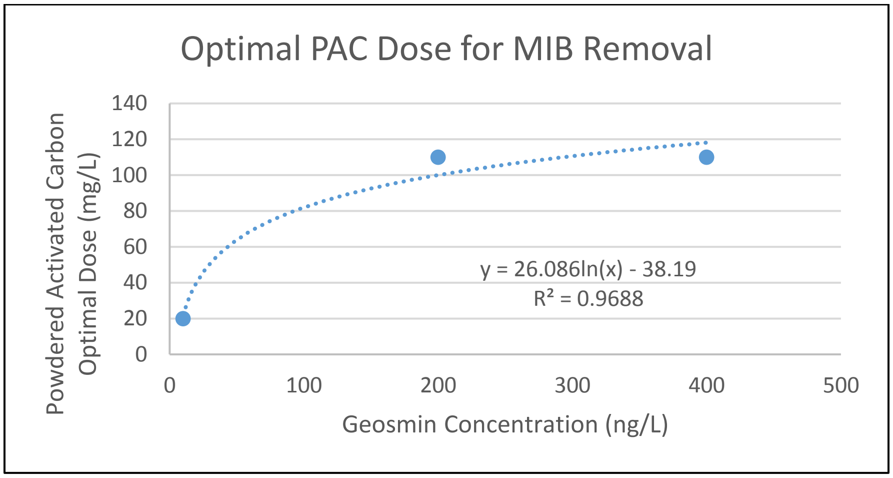
Similarly, two of the jar tests obtained 100% reduction of MIB at the 10 ng/L concentration of MIB. The optimal dose (combination of intake and plant dose) determined was 20 mg/L of PAC. Three jar tests obtained 100% reduction of MIB at the 200 ng/L level and they were all 110 mg/L PAC dose. Only one jar test obtained 100% reduction in MIB at the 400 ng/L level. It was also 110 mg/L. See table below for a summary of test results.

The average combined optimal dose rates for achieving 100% reduction in MIB were compiled in a table based on the concentration of MIB used. The points were plotted on a graph with powdered activated carbon optimal dose in mg/L on the y-axis and MIB concentration (ng/L) on the x-axis. A logarithmic trend line was added and the equation of the line was calculated: $y = 26.086 \ln(x) – 38.19$, where the PAC dose = y and x = MIB concentration. The correlation coefficient or R-squared value was 0.9688.

Table 3: *Optimal PAC Dosages for MIB Removal*

Optimal PAC Dose Curve for MIB Removal	
MIB (ng/L)	Optimal PAC Dose (mg/L)
10	20
200	110
400	110

Figure 3: *Optimal PAC Dose for MIB Removal*



The ultimate goal of this study was to generate a table so that PAC dosing could be determined quickly by treatment facility staff. Therefore, the equations were used with varying geosmin and MIB concentrations from 5 ng/L to 400 ng/L (every 5 ng/L) and the optimal doses were summarized in one table for geosmin and another table for MIB. See the next two pages for the tables.

After the study was completed, the tables were put in to action to decide optimal PAC dosing in the full scale treatment facility. Initially they didn't seem to work. Much more PAC was being fed that what the tables suggested was optimal. Yet the drinking water still had a noticeable taste and odor. Therefore, MIB and geosmin were measured at multiple stages in the treatment process. Geosmin was increasing after it reached the treatment plant and before the filter effluent. It became clear that overfeeding PAC at the intake or at the treatment facility was not going to help. Cleaning the pulsator basins helped to alleviate that problem.

Overall, the findings of this study will be used to: improve the taste and odor of the drinking water, refine and optimize PAC dosing which will save money on the chemical budget, save money on waste processing (centrifuge) expenses, as well as reduce the waste products produced, and understand the importance of tracking sources of taste and odors through treatment process for educated treatment.

Table 4: *Geosmin Optimal Powdered Activated Carbon Dose Table*

Geosmin Optimal Powdered Activated Carbon Dose Table

Geosmin (ng/L)	Optimal PAC Dose (mg/L)	Geosmin (ng/L)	Optimal PAC Dose (mg/L)	Geosmin (ng/L)	Optimal PAC Dose (mg/L)	Geosmin (ng/L)	Optimal PAC Dose (mg/L)
5	4	105	52	205	63	305	69
10	15	110	53	210	63	310	69
15	21	115	54	215	63	315	69
20	26	120	54	220	64	320	70
25	29	125	55	225	64	325	70
30	32	130	55	230	64	330	70
35	35	135	56	235	65	335	70
40	37	140	57	240	65	340	71
45	39	145	57	245	65	345	71
50	40	150	58	250	66	350	71
55	42	155	58	255	66	355	71
60	43	160	59	260	66	360	72
65	45	165	59	265	67	365	72
70	46	170	60	270	67	370	72
75	47	175	60	275	67	375	72
80	48	180	61	280	68	380	72
85	49	185	61	285	68	385	73
90	50	190	61	290	68	390	73
95	51	195	62	295	68	395	73
100	51	200	62	300	69	400	73

Table 5: *MIB Optimal Powdered Activated Carbon Dose Table*

MIB Optimal Powdered Activated Carbon Dose Table

MIB (ng/L)	Optimal PAC Dose (mg/L)	MIB (ng/L)	Optimal PAC Dose (mg/L)	MIB (ng/L)	Optimal PAC Dose (mg/L)	MIB (ng/L)	Optimal PAC Dose (mg/L)
5	4	105	83	205	101	305	111
10	22	110	84	210	101	310	111
15	32	115	86	215	102	315	112
20	40	120	87	220	103	320	112
25	46	125	88	225	103	325	113
30	51	130	89	230	104	330	113
35	55	135	90	235	104	335	113
40	58	140	91	240	105	340	114
45	61	145	92	245	105	345	114
50	64	150	93	250	106	350	115
55	66	155	93	255	106	355	115
60	69	160	94	260	107	360	115
65	71	165	95	265	107	365	116
70	73	170	96	270	108	370	116
75	74	175	97	275	108	375	116
80	76	180	97	280	109	380	117
85	78	185	98	285	109	385	117
90	79	190	99	290	110	390	117
95	81	195	99	295	110	395	118
100	82	200	100	300	111	400	118

REFERENCES

Kerri, K.D., 2006 (5th ed.). Water Treatment Plant Operation Volume I. Office of Water Programs, University Enterprises, Inc., California State University, Sacramento.

Standard Methods for the Examination of Water and Wastewater, 2005 (21st). APHA, AWWA, and WEF, Washington.

Stuff, J., 2016. *Analysis of Odor Compounds in Water by Stir Bar Sorptive Extraction (SBSE)*, GERSTEL Global Analytical Solutions, Baltimore.