RESEARCH ARTICLE **(Open Access)**

Optimizing water treatment practices for the removal of actinomycetes and earthy odor in water of Bovilla reservoir

ADELA KULLAJ*, MARGARITA HYSKO

Department of Biology, Natural Sciences Faculty, Tirana University, Albania.

*Corresponding author e-mail kullajadela@yahoo.com

Abstract

Bovilla reservoir, which is situated 15 km North-East of Tirana the capital city of Albania is one of the major hidrotechnical works of this country. This reservoir is a warm monomictic water body and stratifies higher in the summer season. The predominant trophic state of Bovilla reservoir is oligotrophy. From autumn 2001 this reservoir repeatedly manifests an unpleasant taste and odor which is defined as musty- earthy. Taste and odor control has become an important issue for drinking water suppliers worldwide. Consumers react very sensitively to changes in the organoleptic quality of their drinking water. The reason is that odor compounds present a very low threshold of perception (10–20 ng/L). Bovilla water treatment plant treats 1800 L/s raw water taken from Bovilla reservoir, using oxidation, coagulation and flocculation, sedimentation, filtration and disinfection process. In cases of bad odor powdered activated carbon (PAC) is added at the rapid mix section. Throughout the monitoring period were done: quality and sensory analysis of raw water on a weekly frequency, analysis of treated water after coagulation, laboratory scale experiments using different doses of chemicals, applying optimized doses in full scale and PAC adsorption experiments. The aims of this study were: to predict the PAC doses required to treat water of Bovilla reservoir containing bad taste and odor, to establish the removal efficiency of taste and odor by three types of activated carbons with different iodine number and to assess the impact of NaOCl and other chemical in the treatment process of the plant in removing actinomycetes and bad odor. Results have shown that traditional treatment processes are usually inadequate in removing taste and odor and optimization of plant practices is required. Powdered activated carbon (PAC) can effectively remove taste and odor when the correct dose is applied.

Key words: Bovilla reservoir, water treatment plant, actinomycetes, taste and odor, powdered activated carbon

Introduction

Taste and odor control has become an important issue for drinking water suppliers worldwide. Today, most of the consumer complaints are related to bad taste or odor of drinking water [10]. Musty-earthy odours cause concern among consumers, who may think that water with these odours is unsafe to drink. Consumers react very sensitively to changes in the organoleptic quality of their drinking water because odor compounds present a very low threshold of perception (10–20 ng/L). There is no direct guideline for levels of taste and odor in drinking water. However World Health Organization guidelines [18], require that taste and odor be acceptable to avoid consumer complains.

Bovilla reservoir, which is situated 15 km North-East of Tirana the capital city of Albania is one of the major hidrotechnical works of this country. The reservoir was created to provide for the drinking water supply of Tirana. This reservoir, from autumn 2001 repeatedly manifests an unpleasant taste and odor which is defined as musty- earthy. Musty-earthy odours are the second most common cause of odor problems behind chlorine [17]. Two major off-flavor compounds are geosmin (GSM) and 2-methylisoborneol (MIB). Cyanobacteria [14] and actinomycetes [11] are known to produce both of these compounds. Actinomycetes have long been linked with musty-earthy odours in water [16], but their actual role to odor in freshwater was unknown. In the late 1960s, the earthy-musty odor secondary metabolites geosmin and 2-methylisoborneol (MIB) were identified from actinomycete cultures [5, 6]. Geosmin and other earthy–musty compounds produced in the terrestrial environment may be transported into water by runoff. [15,7,8]. In a study done in 2010-2013 Kullaj *et* al.,2013 [12] show that maximum level of actinomycetes count is associated with maximum levels of FTN (Flavor threshold number). Actinomycetes are very resistant to treatment processes, they can colonize the structures of the drinking water plant through the spores favoring the production of odor-causing compounds in finished water [3] so traditional treatment processes are usually inadequate in removing many of these micropollutants and more advanced processes such as ozonation and activated carbon treatment are required.

Bovilla water treatment plant is using advanced treatment techniques such as treatment with powdered activated carbon (PAC) because of the seasonal incidents of taste and odor. Difficulties with predicting the PAC doses required can result in under-dosing, resulting in consumers complains, and overdosing resulting in acceptable water quality but a very high cost to the water treatment authority [4]. Adsorption capacity is affected by factors including the presence of other compounds that compete for adsorption sites on the activate carbon, the presence of disinfectants which can oxidize the carbons surface, contact time, mixing conditions, point of dosing and the presence of coagulants. The primary objective of this work was the prediction of PAC doses required to treat water of Bovilla reservoir containing bad taste and odor. The aims of this study were to assess the impact of NaOCl and other chemichal in the treatment process of treatment plant in removing actinomycetes and to establish the removal efficiency of taste and odor by three types of activated carbons with different iodine number.

Materials and methods

Water treatment plant

The water utility in the investigated area treats water from Bovilla reservoir and supplies 60% of Tirana city. Bovilla reservoir is a warm monomictic water body and stratifies higher in the summer season. The predominant trophic state of Bovilla reservoir is oligotrophy.The reservoir has a hydraulic residence time 1.5 years. [13] The plant treats 1800 L/s raw water using oxidation, coagulation and flocculation, sedimentation, filtration and disinfection. In cases of bad odor, powdered activated carbon is added at the rapid mix section. Figure 1 gives a simplified overview of the treatment process.

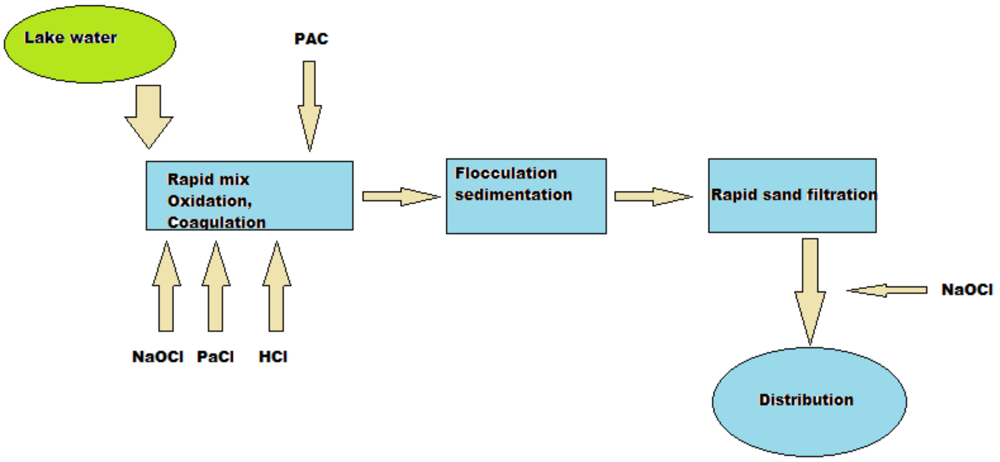

Figure 1. Treatment scheme of raw water in Bovilla plant

Sampling sites and experiments

Three were the sampling sites in WTP (water treatment plant). Site 1 represents raw water taken in the inlet of the plant. Site 2 represents water taken after coagulation, flocculation and sedimentation. Site 3 represents finished water. In the table below are shown the chronology of events and investigations.

Table1. Chronology of events and investigations

Chronology of events and investigations	
Date	**Event**
May 2011-May 2013	Quality and Sensory analysis of raw water on a weekly frequency
May 2011-May 2013	Analysis of treated water after coagulation
September 2013- November 2013	PAC adsorption experiments. Laboratory scale experiments using different doses of chemicals and applying optimized doses in full scale.
September 2013- December 2013	PAC adsorption experiments using three types of PAC

Analyses

Water samples were taken in sterile conditions and were analyzed in the sampling day. The values of turbidity were measured using a turbidimeter (WTW Turb 430IR model). pH value were measured with a pH meter (WTW inoLab multi 740 model) Other parameters analyzed in the laboratory of Bovilla WTP: Water temperature, ammonium, permanganate index, fecal streptococci and actinomycetes. Physical and chemical parameters were analyzed according to Standard Procedures [2]. Fecal streptococci were identified by membrane filtration and was used AZIDE-NPS nutrient media. For the determination of actiomycetes 100 ml of raw water, was used. The water was filtered on a sterile green membrane filter with a pore size of 0.45µm (Whatman). The medium used was actinomycetes NPS (DR . MÖLLER & SCHMELZ GmbH).

Flavor threshold test

Flavor threshold test (FTT) were determined by the dilution method [2]. Samples for determination of FTN (flavor threshold number) were collected from the intake of Bovilla WTP. These samples represented the 20-25 m depth waters of the lake and were analyzed as soon as possible to avoid chemical and biological reactions which may possibly be able to modify the taste of water. A series of eight glass beakers was used. The water sample judged to be with taste was diluted with taste free water to a volume of 200 ml. The water was tested by a panel of six testers. To each tester was presented first the reference water, followed by the most dilute sample. From one to three additional blanks were inserted in the series. The flavor threshold number is the dilution ratio at which flavor is just detectable.

PAC adsorption experiments

In this study three commercially available PACs were employed. The PACs were dried in an oven at 105 ^oC for 24 h, then cooled and stored in a desiccator prior to use. Table 2 lists some characteristics of the PACs tested.

Table 2. Characteristics of powdered activated carbons (PACs) used in this study.

PAC	*Iodine number m/g*	*Density Kg/m^3*	*Ash content %m/m*	*Granulometry<150 µm % m/m*
1	850	480	7.8	98
2	1000	450	6.2	95
3	1190	415	5	100

The removal efficiency of taste and odor of PAC was determined using a jar test procedure. Six 2000-m1 square jar test beakers were used and filled with1000 ml of raw water. A PAC stock solution was prepared (1% = 10000 ppm) and concentrations of 4, 7, 10, 13 and 15 mg/L added to raw water which had taste and odor. The carbon was added to the water while mixing at 300 revolutions per minute for 30 seconds prior to the addition of other chemicals .A control containing no carbon was also prepared. The same coagulant and dose as being used at the plant was added to each jar and the same dose of chlorine and acid at the same concentrations as being used on the plant. Stirring at 300 rpm continued for 5 minutes after the addition of other chemicals. Thereafter the mixing speed was reduced to 60 rpm and stirring continued for 2 hours. The samples were left to settle for another 30 minutes. The water was then filtered through a filter paper (Whatman No. 1 equivalent) and analyzed for taste.

Results and discussion

Quality and Sensory analysis of raw water

In the table below are show quality and sensory parameters of water analyzed in three sites during the monitoring period. This monitoring period implicates two situation of the water quality: One situation with no taste (normal period) and the other situation with earthy taste (taste period). A study [12] have shown that maximum levels of flavor threshold number (FTN) are observed in the same period where actinomycetes are frequent, suggesting an important role on the production of musty-earthy odor. And in fact in our study during the beginning of the bad taste are observed differences in water parameters after coagulation in comparison with the period with no taste. In site 2 of monitoring actinomycetes and fecal streptococci begins to appear. These parameters, when the taste begins have an increasement in the raw water. They survive in floculators because of low concentration of chlorine. Chlorine is added in the rapid mix section of the WTP. In this section after problems of earthy odor occurs, PAC is added. PAC adsorbs the chlorine favoring the development of microorganisms in flocculators.

Table 3. Characteristic of water in three sites of monitoring

Parameter	Unit	Normal period			Taste period		
		Raw water	Water after coagulation	Finished water	Raw water	Water after coagulation	Finished water
Water temperature	^0C	10.8	10.3	10.9	10.92	10.2	11.0
pH		8.08	7.68	7.88	8.03	7.65	7.85
Turbidity	NTU	5.42	0.55	0.01	7.55	1.23	0.01
Permanganate index	mg/LO_2	.95	0.57	0.57	.98	0.61	0.60
Ammonia	mg/L NH_4^+	.025	0	0	.032	0	0
Free residual chlorine	Mg/L Cl	0	0.73	0.88	0	0.09	0.94
Fecal streptococci	Cfu/100 ml	54.27	0	0	120.16	0.32	0
Actinomycetes	Cfu/100ml	16.27	0	0	89.78	0.15	0
FTN		0	0	0	13.18	0.031	0.025

PAC adsorption experiments

PAC adsorption experiments have been carried out during the taste season (September 2013-November 2013). During this period the raw water had a flavor threshold number average 20 FTN. The powdered activated carbon used for that experiment had an iodine number 1000 mg/L.

The jar test procedure was used with the same chemical and doses as being used on the plant in normal conditions. In table 4 are shown results of jar test, using different doses of PAC in order to remove the earthy taste.

Table 4. Jar test results using different PAC doses

Data	*Coagulant mg/L*	*HCl mg/L*	*Chlorine mg/L*	*PAC mg/L*	*% Removal*
Jar 1 control	10	10	3	0	0
Jar 2	10	10	3	4	47
Jar 3	10	10	3	7	78
Jar 4	10	10	3	10	95
Jar 5	10	10	3	13	100
Jar 6	10	10	3	15	100

Raw water: pH=8.15
Turbidity= 13 NTU
Water temperature: 11.9 ^0C
FTN=24

Results have shown that for the removal of taste from the water of Bovilla is needed a PAC dose between 10 and 13 mg/L. The control jar demonstrates that classical method of the water treatment is inadequate in removing earthy taste from water.

Laboratory scale experiments using different doses of chemicals

During the taste season bacterial load in the flocculators is present and the flavor threshold number is higher in comparison with raw water (when the PAC begins to be dosed), for this reason , laboratory scale experiments were done with different doses of chemical in order to remove better the taste. In table 5 are given the results of jar test. In these experiments the dose of PAC was kept 10 mg/L, a value take out from PAC adsorption experiments

Results have shown that increasing the doses of chemical, the odor is removed with e PAC dosage 10 mg/L with 100 % removal efficiency

.

Table 5. Jar test results using different doses of chemicals.

Data	*Coagulant mg/L*	*HCl mg/L*	*Chlorine mg/L*	*PAC mg/L*	*pH*	*Turbidity NTU*	*% Removal*
Jar 1	10	10	3	0	7.73	1.53	0
Jar 2	10	10	5	7	7.75	1.51	83
Jar 3	10	13	5	7	7.63	1.51	90
Jar 4	15	13	5	7	7.54	0.94	93
Jar 5	15	12	5	10	7.51	0.86	100

Raw water: pH=8.18
Turbidity= 10NTU
Water temperature: 11.4 ^{0}C
FTN=24

Table.6 Water parameters after applying optimized doses of chemicals.

Parameter	***Unit***	***Raw water***	***Water after coagulation***	***Finished water***
Water temperature	^{0}C	11.0	10.8	11.1
pH		8.17	7.58	7.83
Turbidity	NTU	10.3	0.88	0.01
Permanganate index	mg/LO_2	.96	0.51	0.50
Ammonia	mg/L NH_4^+	.032	0	0
Free residual chlorine	Mg/L Cl	0	0.20	0.98
Fecal streptococci	Cfu/100 ml	230	0	0
Actinomycetes	Cfu/100ml	84	0	0
FTN		23	0	0

Applying optimized doses in full scale

Optimized dosages are been applied in full scale. Results shown in table 6 are referred to parameters measured after a week treatment with optimized chemicals doses.

Results have shown that during the taste season is necessarily applying higher doses of chemical than in normal period. As the PAC adsorbs the chlorine, higher dose is need for the oxidation and disinfection to occur properly. A higher dose of coagulant and acid is needed to form more flocs to bind the microorganisms. So actinomycetes and fecal streptococci are removed from flocculators, from the bottom by a mechanical sludge removal. The presence of coagulants or chlorine or both enhanced the removal of taste.

PAC adsorption experiments using three types of PACs.

The AWWA standard for PAC specifies a minimum iodine number of 500 mg/g [1]. WTP of Bovilla uses an activated carbon with an iodine number minimally 900 mg /L. In our study a jar test procedure is done to establish the removal efficiency of taste and odor by three types of activated carbons with different iodine number. Results have shown that a PAC with high iodine number removes better the earthy taste from water (Table 7). However, a high iodine number is not necessarily an indication that a PAC will be effective in adsorbing the target compounds. A study has shown [9] that a high iodine number is not a guarantee of effective geosmin removal. In case of Bovilla water, taste removal efficiency was related with the iodine number of powdered activated carbon.

Table.7 Effective removal dose and with iodine number.

PAC	*Iodine number mg/g*	*Effective removal dose mg/l*
1	850	13
2	1000	10
3	1190	7

Conclusions

This study provided important information in optimizing water treatment practices for the effective removal of earthy taste from water. Results from this study indicate that:

- Traditional water treatment practices are inadequate in removing bad taste from water.
- During the taste season, WTP necessarily should apply higher doses of chemical than in normal period in order to remove the taste.

- Powdered activated carbon (PAC) can effectively remove taste and odor when the correct dose is applied.
- In this study a jar test procedure was used to predict the PAC dose without the need to analyze compounds that are related with earthy odor like geosmin and MIB, avoiding the need of gas chromatograph (GC) and mass spectrometer (MS). Since consumer complaints are derived from the smell of the water and the effect is only aesthetic, with no health dangers, one needs only to determine the PAC dose required odor reduction of the water below the human threshold concentration and this can be done using sense of smell.

References

1. American Water Works Association (AWWA), **Standard for Powdered Activated Carbon** ANSI/AWWA B600-90, USA, 1991.
2. APHA (Ed.): **Standard Methods for the Examination of Water and Wastewater. 20th Edition**. American Public Health Association, Washington, DC. 1998
3. Bao M.L, Barbieri K, Burrini D, Griffini O & Pantani F: **Determination of trace levels of taste and odor compounds in water by microextraction gas chromatography-ion-trap detection-mass spectometry**. Wat. Res. 1997, 31(7), 1719–1727.
4. Cook D, Newcombe, G, Sztajnbok P : **The application of powdered activated carbon for MIB and geosmin removal: predicting PAC doses in four raw waters**. Wat. Res. 2001,Vol. 35, No. 5, pp. 1325±1333, 2001
5. Gerber N.N: **Volatile substances from actinomycetes; their role in the odor pollution of water.** Water Sci. Technol. 1983, 15 (6–7), 115–125.
6. Gerber N.N, Lechevalier H.A: **Geosmin, an earthy-smelling substance isolated from actinomycetes.** Appl. Microbiol. 1965, 13 (6), 935–938.
7. Hrudey S.E, Rector D, Motkoski N: **Characterization of drinking water odor arising from spring thaw for an icecovered upland river source.** Water Sci. Technol. 1992, 25 (2), 65-72
8. Jensen S.E, Anders C.L, Goatcher L.J, Perley T, Kenefick S.E, Hrudey S.E: **Actinomycetes as a factor in odor problems affecting drinking water from the North Saskatchewan River.** Water Res. 1994, 28:1393-1401.
9. Linde J.J, Freese S.D, S Pieterse:**Evaluation of powdered activated carbon (PAC) for the removal of taste and odor causing compounds from water and the relationship between this phenomenon and the physico-chemical properties of the pac and the role of water quality.** WRC Report No. 1124/1/03
10. Khiari D; Bruchet A; Gittelman T; Matia L; Barrett S; Suffett I.H; Hund R: **Distribution-generated taste-and-odor phenomena**, *Water Sci. Technol.* 1999, *40 (6)*, 129-133
11. Klausen C, Nicolaisen M.H, Strobel B.W, Warnecke F, Nielsen J.L and Jorgensen N.O.G: **Abundance of actinobacteria and production of geosmin and 2-methylisoborneol in Danish streams and fish ponds.** FEMS Microbiology Ecology. 2005, 52 (2): 265-278.
12. Kullaj A, Hysko *M.:* **Taste and odor episodes in water of bovilla reservoir used for the water supply of tirana** . 5th International Symposium of Ecologist of Montenegro (**ISEM5**). Tivat 2-5 October 2013.
13. Miho A, Çullaj A, Bachofen R: **Bovilla (Albania) Studim Limnologjik**. SCOPES program 2005-2008 (Scientific Cooperation between Eastern Europe and Switzerland). 2009.
14. Persson P.E**:Cyanobacteria and off-flavours.** Phycologia. 1996. 35 (6): 168-171.
15. Raschke R.L, Carroll B, Tebo L.B: **The relationship between substrate content, water quality, actinomycetes and musty odours in the broad River basin.** J. Appl.Ecol. 1975, 12 (2), 535-560.
16. Silvey J.K.G, Roach A.W: **Actinomycetes in the Oklahoma City water supply.** J. Am. Water Works Assoc. 1953, 45, 409–416.
17. Suffett I.H, Corado A, Chou D, McGuire M.J.M, Butterworth S: **AWWA taste and odor survey.** J. Am. Water Works Assoc. 1996, 88 (4), 168–180.
18. World Health Organization: **Guidelines for drinking-water quality, vol.1. Recommendations, 2nd ed.** World Health Organization, Geneva, Switzerland. 2004.