
MONITORING AND TREATMENT OF VOLATILE ORGANIC COMPOUNDS IN DRINKING WATER COMPARATIVE STUDY

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ABSTRACT

Volatile organic compounds (VOCs) present in drinking water, have a negative impact on human health and environment especially that formed during chlorination step in the treatment process, they classified as possible human carcinogens, when exceed the permissible limits. The identification and quantification of VOCs performed by purge & trap GC/MS instrument, using reference analytical method (**EPA 524.2, 1995**). A monthly monitoring comparative study established during 2016 in both input and output of Shubra El-Kheima (Water Treatment Plants WTP) (1 km far from Nile River on Al-Sharqawia canal at the northern border of capital Cairo) and South Alamein WTP (270 km downstream far from the Nile River on Alhamam canal at North Coast of Egypt). The study investigated and recorded the presence of disinfection by-product of Volatile Organic Compounds (DBPs-VOCs) (CHCl_3 , CHCl_2Br , CHClBr_2 and CHBr_3) which exceeded the permissible limits in the produced Water of South Alamein WTP and its boosters. The study succeeded in estimating the amount of granular activated carbon GAC required to reduce (DBPs-VOCs) values from (178 $\mu\text{g/l}$) to (94 $\mu\text{g/l}$) in the produced water of South Alamein WTP, The duration frequency for changing (GAC) would be approximately (581 ton)/(17 days).

Key words: Volatile organic compounds, granular activated carbon, drinking water, disinfection by-product, GC/MS analysis

INTRODUCTION

Volatile organic compounds (VOCs) are a group of organic compounds containing one or more carbon atoms and whose vapor pressures are high enough to cause them to readily volatilize into the atmosphere conditions (Ikem, 2010). Due to the industrial revolution, many activities, such as petroleum industry, have emitted anthropogenic pollutants including toxic gases and volatile organic compounds (VOCs) (Hailin *et al.*, 2013). VOCs can produce from,

1. Industrial Chemicals discharge and human dwellings: Such as: 1,3-dichlorobenzene, ethylbenzene, 1,1-dichloroethane, 1,1-dichloroethene, hexachlorobenzene, dichloroethene, dichloromethane, methyltertiary-butylether, monochlorobenzene, trichlorobenzenes, 1,1,1-trichloroethane, benzene, Carbon tetrachloride, 1,2-dichlorobenzene, 1,4-dichlorobenzene, 1,2-dichloroethane, 1,2- hexachlorobutadiene, styrene, tetrachloroethene, toluene, trichloroethene, xylenes.

2. Agricultural activity: Such as: 1,2-dibromo-3-chloropropane, 1,3-dichloropropene, 1,2-dichloropropane, 1,2-dibromoethane.

3. Disinfection processes with chlorine: Such as: chloroform, bromodichloromethane, dibromochloromethane and bromoform (**WHO, 2011**).

In 1881, a German named Koch showed the role of bacteria in waterborne diseases. Koch demonstrated that minute quantities of chlorine could inactivate harmful waterborne pathogens. The introduction of chlorination resulted in significant decreases in worldwide waterborne

diseases, such as typhoid, (Haas and Aturaliye, 1999). Chlorine is the most widely and easily used as disinfectant, and the most affordable of the drinking water disinfectants. Similarly, it is an affordable oxidant (WHO, 2004). The most common form of chlorine for use in water treatment plants is the chlorine gas, it is very strong oxidizing agent (more powerful than oxygen), easy to feed, effective disinfection and has a long history of use to reduce water born disease by inactivating harmful microorganism (Salama, 2004). Disinfection by-products DBPs formed due to a reaction between a disinfecting agent (chemical or physical) and a precursor chemical in the source water. The factors affecting formation of DBPs are chlorine residual, contact time, pH, temperature, and natural organic matters NOMs. Chlorine dose from 2.0 to 16.0 mg/L will lead to an increase of reactions, therefore causing an increase of trihalomethanes THMs and haloacetic acids HAAs formation (Sun *et al.*, 2009). Volatile organic compounds (VOCs) including (THMs) may present in bottled and tap waters at unacceptable concentrations. Several research articles have reported the occurrence of industrial chemicals or disinfection by-products (DBPs) in source, bottled and tap waters (Leivadara *et al.*, 2008; Panyakapo *et al.*, 2008; Wang *et al.*, 2007; Kavcar *et al.*, 2006; Uyak, 2006; Kruawal *et al.*, 2005; Panyapinyopol *et al.*, 2005). Natural organic matter (NOM) is present in all surface, ground waters and soil. NOMs consist of a wide range of compounds, from largely aliphatic to highly colored and aromatic, as well as highly charged to uncharged, having also a wide variety of chemical compositions and molecular sizes. The amount of NOM in water differs with climate and the hydrological regime as well as a number of other environmental factors. Thus, the character of NOM

can vary with source and time (season). The main compound of interest is bromodichloromethane, which may be responsible for carcinogenic activity in drinking water while chloroform is cytotoxic and non-carcinogenic at environmental concentrations. Some industrial chemicals such as vinyl chloride, methylene chloride, toluene, ethylbenzene, m-xylene, p-xylene, o-xylene, naphthalene may be found in drinking waters due to contamination during the process of production (Water Quality Report, 2007).

Egyptian ministry of health approved guideline values for some VOCs like, vinyl chloride: 0.3 $\mu\text{g/L}$, 1,1-dichloroethene: 30 $\mu\text{g/L}$, 1,2-dichloroethene 50 $\mu\text{g/L}$, 1,1,1-trichloroethane 70 $\mu\text{g/L}$, carbontetrachloride 4 $\mu\text{g/L}$, benzene 10 $\mu\text{g/L}$, trichloroethene 20 $\mu\text{g/L}$, 1,2-dichloropropane 20 $\mu\text{g/L}$, toluene 700 $\mu\text{g/L}$, tetrachloroethene 40 $\mu\text{g/L}$, 1,2-dibromoethane 30 $\mu\text{g/L}$, chlorobezene 300 $\mu\text{g/L}$, ethyl benzene 300 $\mu\text{g/L}$, xylene 500 $\mu\text{g/L}$, styrene 20 $\mu\text{g/L}$, 1,4-dichlorobenzene 300 $\mu\text{g/L}$, 1,2-dichlorobenzene 1000 $\mu\text{g/L}$, 1,2-dibromo 3-chloropropane 1 $\mu\text{g/L}$, trichlorobenzene 20 $\mu\text{g/L}$, hexachlorobutadiene 0.6 $\mu\text{g/L}$ and total trihalomethanes (CHCl_3 , CHBrCl_2 , CHBr_2Cl and CHBr_3) 100 $\mu\text{g/L}$ which represent the values of VOCs produced from the disinfection process in this study (Egyptian guidelines, 2007).

The aim of this study is monitoring of VOCs in raw and drinking water of Shubra Al-Kheima and South Alamein WTP, and to find an appropriate way to reduce VOCs when exceeds the permissible limits.

MATERIALS& METHODS

1 Monitoring of VOCs in Shubra Al-Kheima and South Alamein WTP:

A comparative study between two water treatment plants, both of them are depending on surface water from the Nile River as original source. The first (Shubra El-Kheima WTP) is located in the nearest point of Nile River branch (1 km, On Al-Sharqawia canal) at north of capital city (Cairo) to evaluate the maximum load content of VOCs in the far north point of capital either that coming from industrial discharge on the surface water or that formed during the disinfection process. This plant covering an area of (10 km) distance far from it. The second (South Alamein WTP) is located in the extremist point of Nile River branch (270 km, On Al-Hammam canal) at South Alamein in the north coast of Egypt (285 km far from the first location) to evaluate the maximum load of VOCs accumulated along this distance and comparing the results of the two selected plants. From the other hand the second plant is covering an area of 190 km far from the treatment plant which pumping the produced treated water through closed pipes using 6 boosters. Another comparative study will be carried out on the output water of each booster to assess the effect of distance (more contact time with residual chlorine) on disinfection by-product of volatile organic compounds DBPs-VOCs formation. A survey of VOCs monitoring performed in raw water and final treated water (output) for both Shubra Al-Kheima & South Alamein WTPs and its boosters.

2 Removal of Voss using Granular Activated Carbon (GAC)

2.1 FIXED-BED Column studies: A continuous flow (laboratory scale apparatus), shown in Fig (1) was used to reduce VOCs in the final treated water of South Alamein WTP that produced in August 2017 (which recorded the highest levels of VOCs). *1st*, The final treated water was introduced into the glass column packed with GAC, the flow rates of output water is controlled by a fine restrictor at the end of the glass column and consequently a different contact time with GAC could be applied (from 0.5 min to 21 min). A relation between contact time and % removal was plotted to choose the appropriate contact time that could be applied on South Alamein WTP. *2nd*, another experiment was carried out on the final produced water of South Alamein WTP during August 2017 using the same apparatus and applying the obtained appropriate contact time. A breakthrough curve for (CHCl_3 , CHBrCl_2 , CHBr_2Cl , CHBr_3 and TOC) plotted to determine the volume at which the amount of GAC would be exhausted for each 5examined parameters.

Materials

VOCs analyzer, Varian GC/MS-Detector (Ion Trap 4000) equipped with purge & Trap unit.

TOC Analyzer Tekmar-Teledyne (Phoenix 8000 UV Persulfate-USA)

A continuous flow apparatus consists of glass column packed with Granular Activated Carbon (GAC) (Chemviron-grade 207EA 12.5*40 US mesh size), the internal diameter of the column is 2 cm and 45 cm length, the

column is filled with 25 g GAC (mesh size 12 x 40 US, bed depth H was 16 cm and density 485 kg/ton). Fig 1

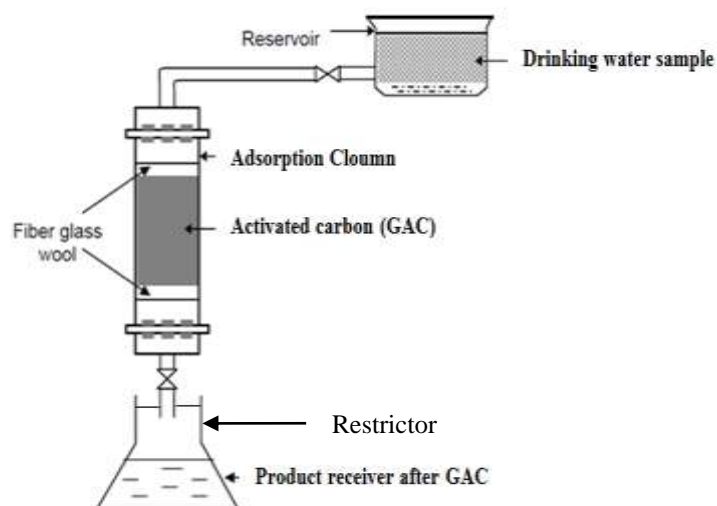


Figure (1): Continuous flow Glass column (laboratory scale setup).

Methods:

Samples collected from field in 40 ml tightly sealed amber glass bottles. Finally treated drinking water samples, for VOCs preserved by adding 3 mg sodium thiosulfate to stop the reaction of chlorine, 5 ml aliquot injected directly into a Spurger and purged for 11 min then injected to the GC/MS-Ion trap.

VOCs and TOC were monthly monitored and quantified in Shubra Al-Kheima & South Alamein WTPs, according to (EPA 524.2, 1995), (Standard method 5310C, 2012) respectively.

RESULTS AND DISCUSSIONS

3 Monitoring of VOCs & TOC

3.1 In Shubra El-Kheima WTP: Monthly monitoring of VOCs (55 species) according to reference method (EPA 524.2, 1995) (Table, 1) and TOC was applied in both raw water (Intake) and final treated water (Product) during 2016.

Table 1: Examined VOCs According to reference method (EPA 524.2, 1995)

Hexachlorobutadiene	1,2-Dichloroethane	n-Butylbenzene	Dichlorodifluoromethane
Vinyl chloride	Trichloroethene	Ethyl benzene	1,2,4 Trimethylbenzene
1,3 Dichlorobezene	1,2-dichloropropane	P-Xylene+M-Xylene	1,3,5Trimethylbenzene
1,1-Dichloroethene	Dibromomethane	O-Xylene	Bromodichloromethane
P-Isopropyletoluene	1,2 Dichlorobezene	Styrene	Trans1,2-Dichloroethene
1,1-Dichloroethane	1,4 Dichlorobenzene	Bromoform	Trichloromonofluoromethane
2,2-Dichloropropane	Toluene	Isopropylbenzene	Trans1,3-dichloropropene
Cis1,2-Dichloroethene	Cis1,3-dichloropropene	Bromobenzene	1,2,3Trichloropropane
Bromochloromethane	1,1,2-Trichloroethane	Naphthalene	1,2-Dibromo-3-Chloropropane
Chloroform	Tetrachloroethene	Sec-Butylbenzene	1,2,4 Trichlorobenzene
1,1,1-Trichloroethane	1,3 Dichloropropane	N-Propylbenzene	1,1,1,2-Tetrachloroethane
Carbon tetrachloride	Dibromochloromethane	2-Chlorotoluene	1,2,3-Trichlorobenzene
1,1-Dichloropropene	1,2-Dibromoethane	4-Chlorotoluene	1,1,2,2-Tetrachloroethane
Benzene	Chlorobenzene	Ter-Butylbenzene	

Fig (2) shows the absence of the targeted fifty-five VOCs species in the raw water which indicates that (there is no industrial waste load enough to affect the levels of VOCs in this area during the study period), as the main source of VOCs in raw water is industrial waste.

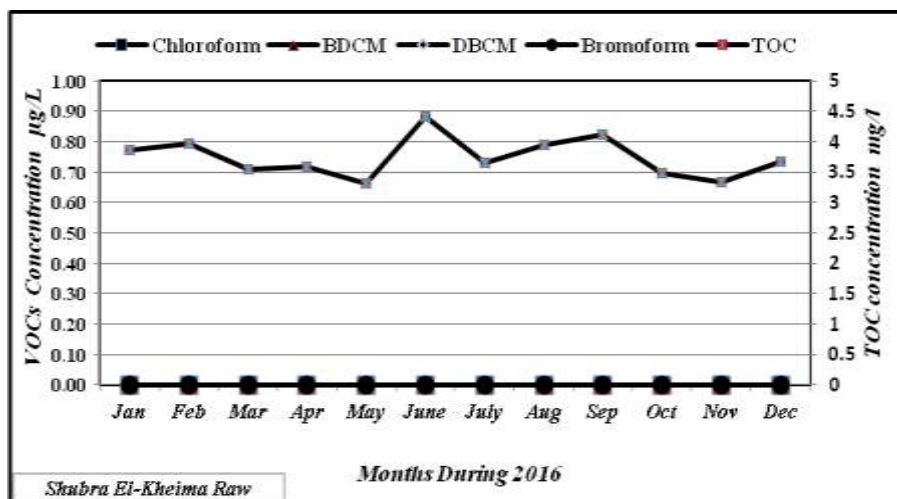


Figure (2): Monthly VOCs & TOC levels variation in raw water of Shubra El-Kheima WTP during 2016.

Fig (3) shows the absence of fifty-one VOCs species from the final produced water of Shubra El-Kheima WTP, while the four rest compounds of DBPs-VOCs (CHCl_3 , CHBrCl_2 , CHBr_2Cl and CHBr_3) showed different levels below the permissible limits of Egyptian guidelines during the study period. These levels were due to the addition of chlorine gas as a disinfectant to raw water in the presence of NOMs which indicated by (Total Organic Carbon TOC) in the Studied plant (Shubra El-Kheima). In addition, Fig (3) shows that the maximum levels of these compounds were recorded in Oct. 2016 as follows (CHCl_3 62.88 $\mu\text{g/l}$, CHBrCl_2 19.69 $\mu\text{g/l}$, CHBr_2Cl 5.82 $\mu\text{g/l}$

and CHBr_3 2.26 $\mu\text{g/l}$). Levels of the previous compounds increased because of increasing NOMs (TOC 4.18 mg/l) during this month. The minimum levels of these compounds were recorded in May 2016 as follows (CHCl_3 24.97 $\mu\text{g/l}$, CHBrCl_2 13.21 $\mu\text{g/l}$, CHBr_2Cl 3.73 $\mu\text{g/l}$ and CHBr_3 0.81 $\mu\text{g/l}$) because of decreasing of NOMs (TOC 3.22 mg/l) during this time of year. (Fig, 3)

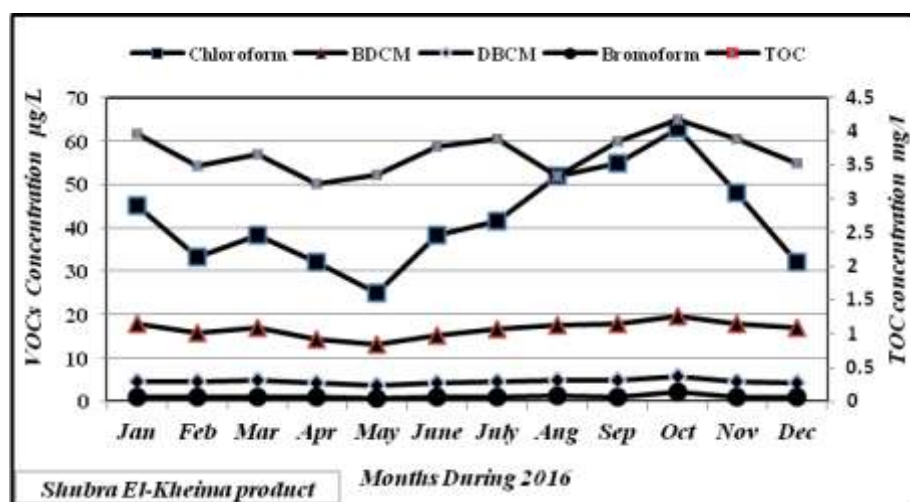


Figure (3): Monthly VOCs & TOC levels variation in produced water of Shubra El-Kheima WTP during 2016.

3.2 In South Alamein WTP: Monthly monitoring of targeted VOCs & TOC was applied in both Raw water (Intake) and final treated water (Product) during 2016.

Fig (4) shows the absence of fifty four VOCs compounds during study period in raw water, while the rest compound (Benzene) detected at levels below the maximum permissible limit of Egyptian guidelines at months of (Jan, Feb, and Dec) due to the presence of many water suction pumps along

El-Hammam canal banks for agriculture purposes which met the winter blockage.

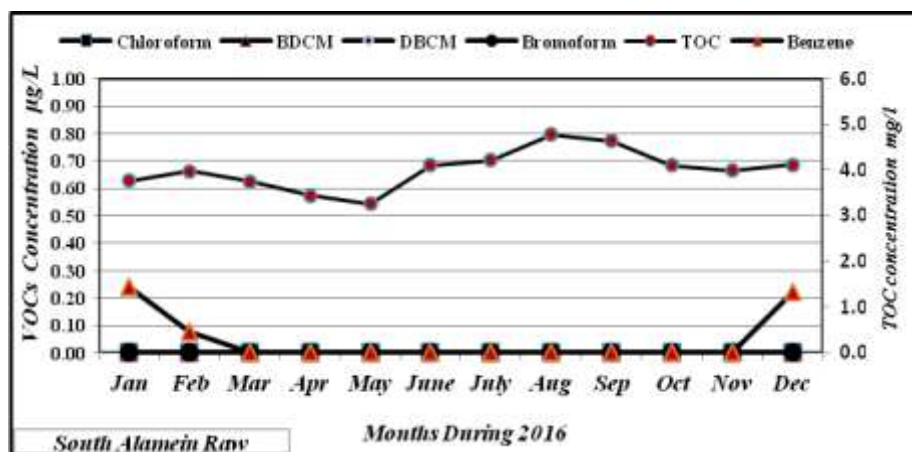


Figure (4): Monthly VOCs & TOC levels variation in raw water of South Alamein WTP during 2016.

Fig (5) shows the absence of fifty-one VOCs species from the final produced water of South Alamein WTP, while the four rest compounds of DBPs-VOCs (CHCl_3 , CHBrCl_2 , CHBr_2Cl and CHBr_3) showed different levels above the permissible limits of Egyptian guidelines during the study period. These high levels were due to the addition of chlorine gas as a disinfectant to raw water in the presence of NOMs in the Studied plant (South Alamein). In addition, Fig (5) shows that the maximum levels of these compounds were recorded in August 2016 as follows (CHCl_3 85.02 $\mu\text{g/l}$, CHBrCl_2 63.28 $\mu\text{g/l}$, CHBr_2Cl 39.70 $\mu\text{g/l}$ and CHBr_3 5.17 $\mu\text{g/l}$). Levels of the previous compounds increased because of increasing of NOMs (TOC 4.51 mg/l) during this month. The minimum levels of these compounds recorded

in May 2016 as follows (CHCl₃ 35.67 µg/l, CHBrCl₂ 26.42 µg/l, CHBr₂Cl 21.32 µg/l and CHBr₃ 2.44 µg/l) due to decreasing of NOMs (TOC 3.36 mg/l) during this time of year.

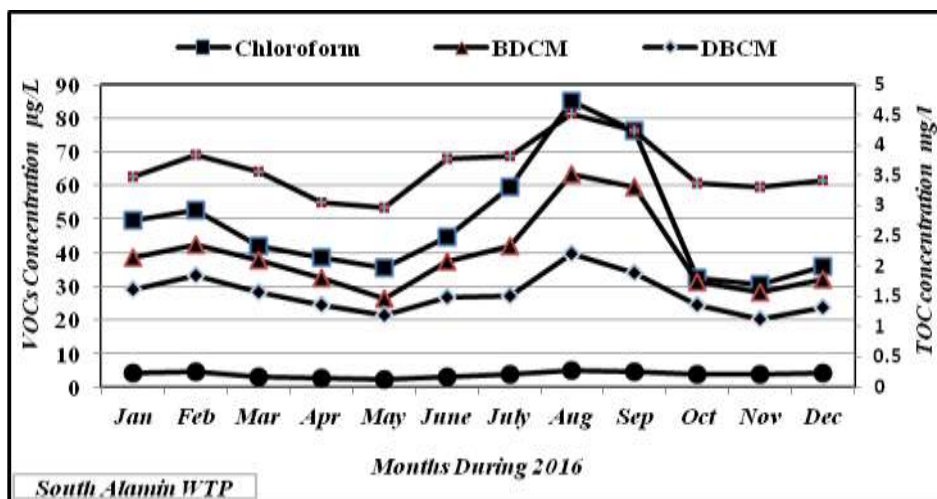


Figure (5): Monthly VOCs & TOC levels variation in produced water of South Alamein WTP during 2016.

4 Removal of DBPs-VOCs from the Produced water of South Alamein TWP:

Using a bench scale Continuous flow Glass column (2 cm I.D), backed with 25 g GAC of height 16 cm (Fig, 1). Different contact times applied to the produced water from south Alamein WTP with GAC (from 0.5 min to 21 min) during August 2017 (monitoring results showed that the maximum level of DBPs-VOCs recorded in August 2016). A relation between contact time and % removal of DBPs-VOCs & TOC (as a main precursor of the produced DBP-VOCs) was plotted.

From Fig (6), we find that the appropriate contact time is 10.0 min (0.166 hr), (with respect to both the % removal of DBPs-VOCs and TOC). As the maximum output 172000 m³/day, total surface area of 14 working GAC filters are 498.75 m², and consequently the linear velocity is 14.37 m/hr (total output per hour/total surface area of GAC filters) for South Alamein WTP. The corresponding depth of GAC that give a contact time, (10 min), will be 2.4 m [Linear velocity (m/h) x appropriate contact time (0.166 hr)].

Table (2): % removal of analytes from produced water of South Alamein WTP with different contact time with GAC in glass column during August 2017.

No	Sample Name	Contact Time (min)	TOC			CHCl ₃		CHBr CL ₂		CHBr ₂ CL		CHBr ₃	
			mg/l	Amount Removed mg/l	% Removal	µg/l	% Removal	µg/l	% Removal	µg/l	% Removal	µg/l	% Removal
1	Blank Before GAC		0.03			0.00		0.00		0.00		0.00	
2	Blank After GAC	30.00	0.02			0.00		0.00		0.00		0.00	
3	Alamine Product Before GAC		4.50			80.00		58.00		36.00		4.90	
4	South Alamein WTP Product After GAC	0.50	3.50	1.00	24.2	5.48	93.2	2.46	95.8	1.72	95.2	0.12	97.6
5		0.75	3.25	1.25	29.7	3.46	95.7	1.32	97.7	0.53	98.5	0.01	99.8
6		1.50	2.98	1.52	35.5	1.81	97.7	0.44	99.2	0.04	99.9	0.00	100.0
7		2.50	2.51	1.99	45.7	1.17	98.5	0.03	99.9	0.00	100.0	0.00	100.0
8		4.00	2.03	2.47	56.1	0.36	99.6	0.00	100.0	0.00	100.0	0.00	100.0
9		5.00	1.64	2.86	64.5	0.02	100.0	0.00	100.0	0.00	100.0	0.00	100.0
10		6.00	1.30	3.20	71.9	0.00	100.0	0.00	100.0	0.00	100.0	0.00	100.0
11		7.70	0.98	3.52	78.8	0.00	100.0	0.00	100.0	0.00	100.0	0.00	100.0
12		10.00	0.69	3.81	85.1	0.00	100.0	0.00	100.0	0.00	100.0	0.00	100.0
13		15.00	0.59	3.91	87.2	0.00	100.0	0.00	100.0	0.00	100.0	0.00	100.0
	21.00	0.54	3.96	88.3	0.00	100.0	0.00	100.0	0.00	100.0	0.00	100.0	

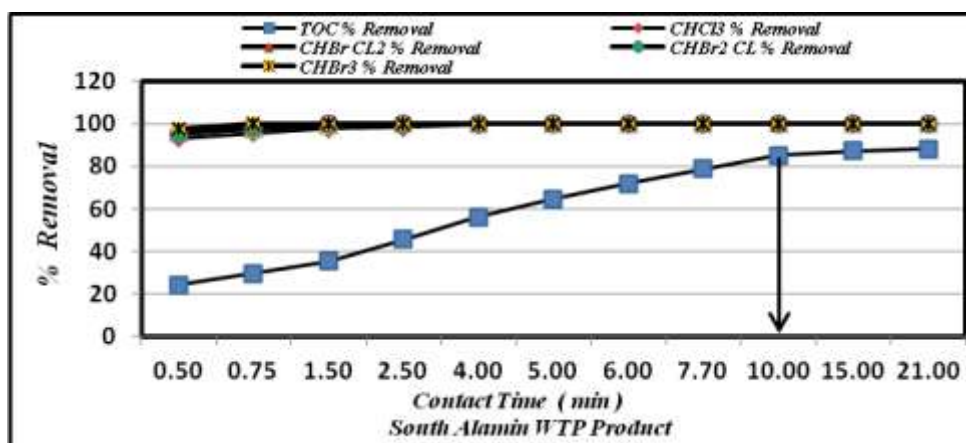


Figure (6): % removal variation of Analytes from produced water of South Alamein WTP with different contact time with GAC in glass column during August 2017.

4.1 FIXED-BED Column studies on South Alamein WTP: The produced drinking water from South Alamein WTP (during August 2017) passed through the continuous flow glass apparatus (2 cm ID); packed with 25 g GAC, GAC bed depth height was 16 cm, Fig (1). The flow rate adjusted using a fine restrictor at the end of column to 5 ml/min (7.2 L/Day), and contact time (10.0 min). A daily water samples collected from the container of the column output (7.2 L/day) to measure (DBPs-VOCs) and TOC for estimating the maximum adsorption capacities for each parameter with GAC, and the volume of water at which GAC well be exhausted for each parameter. The initial concentrations of each parameter measured daily before entering the column, and the mean values at the end of experiment taken as the initial concentration C_0 in the calculations.

Table (3) shows the results of this experiment, where x is the amount of adsorbate from 7.2 L, x/m is the mass of adsorbate from 7.2 L per unit mass of adsorbent (mg adsorbate/g GAC).

Fig (7) shows a breakthrough diagram for the total parameters of DBPs-VOCs.

Adsorption capacity (q_e), is the amount of DBPs-VOCs adsorbed on GAC in equilibrium calculated as follows:

$$q_e = \frac{(C_0 - C_e) V}{W},$$

Where q_e (mg/g) or ($\mu\text{g/g}$) is the amount of analyte adsorbed at equilibrium. C_0 and C_e (mg/l) or ($\mu\text{g/l}$), are the liquid-phase concentrations of DBP-VOCs at initial and equilibrium conditions, respectively. (V) Is the volume of the solution and W (g) is the mass of activated carbon used.

Table (3): Equilibrium concentrations C_e of Analytes from produced water of South Alamein WTP and the amount adsorbed per unit mass of GAC at constant contact time 10 min with GAC in glass column during August 2017.

Maximum adsorption capacity at flow rate 5 ml/min (7.2 L/Day) and contact time 10 min with adsorbent (GAC) through 40 days																					
No	Date	Total Volume (L)	C_0 (TOC) mg/l	X mg/7.2 L	X/m mg/g GAC	C_e (CHCl ₃) µg/l	X µg/7.2 L	X/m µg/g GAC	C_e (CHBrCl ₂) µg/l	X µg/7.2 L	X/m µg/g GAC	C_e (CHBr ₂ Cl) µg/l	X µg/7.2 L	X/m µg/g GAC	C_e (CHBr ₃) µg/l	X µg/7.2 L	X/m µg/g GAC	C_e (DBPs-VOCs) µg/l	X µg/7.2 L	X/m µg/g GAC	Sum Of (DBPs-VOCs) µg/g GAC
C_0 Initial Con.		4.3-4.6				76-82			56-60			35-38			4.7-5.1						When C_e mean reduced to 94 µg/l
C_0 Mean of Initial Con.		4.45				79			58			36.5			4.9			178.4			
1	01-08-17	7.2	0.65	27.36	1.09	0.00	568.80	22.75	0.00	417.60	16.70	0.00	262.80	10.51	0.00	35.28	1.41	0.00	1284.5	51.38	908.64 µg DBPs-VOCs/g GAC
2	02-08-17	14.4	0.68	27.14	1.09	0.37	566.14	22.65	0.00	417.60	16.70	0.00	262.80	10.51	0.00	35.28	1.41	0.37	1281.8	51.27	
3	03-08-17	21.6	0.71	26.93	1.08	0.95	561.96	22.48	0.04	417.31	16.69	0.00	262.80	10.51	0.00	35.28	1.41	0.99	1277.4	51.09	
4	04-08-17	28.8	0.75	26.64	1.07	1.49	558.07	22.32	0.43	414.50	16.58	0.00	262.80	10.51	0.00	35.28	1.41	1.92	1270.7	50.83	
5	05-08-17	36	0.79	26.35	1.05	2.08	553.82	22.15	1.13	409.46	16.38	0.00	262.80	10.51	0.00	35.28	1.41	3.21	1261.4	50.45	
6	06-08-17	43.2	0.84	25.99	1.04	2.81	548.57	21.94	1.36	407.81	16.31	0.00	262.80	10.51	0.00	35.28	1.41	4.17	1254.5	50.18	
7	07-08-17	50.4	0.89	25.63	1.03	3.64	531.07	21.74	2.06	402.77	16.11	0.00	262.80	10.51	0.00	35.28	1.41	7.30	1231.9	49.28	
8	08-08-17	57.6	0.95	25.20	1.01	4.49	501.91	20.08	2.94	386.43	15.86	0.01	262.73	10.51	0.00	35.28	1.41	12.24	1196.4	47.85	
9	09-08-17	64.8	1.07	24.34	0.97	5.36	471.17	18.85	4.03	388.58	15.34	0.01	262.73	10.51	0.00	35.28	1.41	17.60	1157.8	46.31	
10	10-08-17	72	1.13	23.90	0.96	6.25	453.82	18.15	5.54	377.71	15.11	0.02	262.66	10.51	0.00	35.28	1.41	21.53	1129.5	45.18	
11	11-08-17	79.2	1.19	23.47	0.94	7.14	434.59	17.38	7.24	365.47	14.62	0.02	262.66	10.51	0.00	35.28	1.41	25.90	1098.0	43.92	
12	12-08-17	86.4	1.26	22.97	0.92	8.03	407.09	16.28	8.72	354.82	14.19	0.03	262.58	10.50	0.00	35.28	1.41	31.21	1059.8	42.39	
13	13-08-17	93.6	1.32	22.54	0.90	8.92	379.94	15.20	10.28	343.58	13.74	0.04	262.51	10.50	0.00	35.28	1.41	36.55	1021.3	40.85	
14	14-08-17	100.8	1.41	21.89	0.88	9.81	357.05	14.28	12.87	324.94	13.00	0.05	262.44	10.50	0.00	35.28	1.41	42.33	979.7	39.19	
15	15-08-17	108	1.49	21.31	0.85	10.70	331.56	13.26	14.38	314.06	12.56	0.07	262.30	10.49	0.00	35.28	1.41	47.40	943.2	37.73	
16	16-08-17	115.2	1.58	20.66	0.83	11.59	308.27	12.73	16.49	298.87	11.95	0.09	262.15	10.49	0.00	35.28	1.41	54.85	889.6	35.58	
17	17-08-17	122.4	1.67	20.02	0.80	12.48	266.98	10.68	18.62	283.54	11.34	0.11	262.01	10.48	0.00	35.28	1.41	60.65	847.8	33.91	
18	18-08-17	129.6	1.76	19.37	0.77	13.37	232.34	9.29	20.71	268.49	10.74	0.13	261.86	10.47	0.00	35.28	1.41	67.57	798.0	31.92	
19	19-08-17	136.8	1.92	18.22	0.73	14.26	203.33	8.13	22.67	254.38	10.18	0.16	261.65	10.47	0.00	35.28	1.41	73.59	754.6	30.19	
20	20-08-17	144	2.03	17.42	0.70	15.15	168.55	6.74	23.77	246.46	9.86	0.19	261.43	10.46	0.00	35.28	1.41	79.55	711.7	28.47	
21	21-08-17	151.2	2.12	16.78	0.67	16.04	134.14	5.37	26.03	230.18	9.21	0.22	261.22	10.45	0.00	35.28	1.41	86.62	660.8	26.43	
22	22-08-17	158.4	2.28	15.62	0.62	16.93	99.65	3.99	28.84	209.95	8.40	0.25	261.00	10.44	0.00	35.28	1.41	94.25	605.9	24.24	
23	23-08-17	165.6	2.42	14.62	0.58	17.82	58.18	2.33	30.95	194.76	7.79	0.27	260.86	10.43	0.00	35.28	1.41	102.14	549.1	21.96	
24	24-08-17	172.8	2.59	13.39	0.54	18.71	29.30	1.17	33.42	176.98	7.08	0.29	260.71	10.43	0.00	35.28	1.41	108.64	502.3	20.09	
25	25-08-17	180	2.72	12.46	0.50	19.60	7.99	0.32	35.29	163.51	6.54	0.31	260.57	10.42	0.00	35.28	1.41	113.49	467.4	18.69	
26	26-08-17	187.2	2.84	11.59	0.46	20.49			37.34	148.75	5.95	0.33	260.42	10.42	0.00	35.28	1.41	116.67	444.5	17.78	
27	27-08-17	194.4	2.94	10.87	0.43	21.38			39.46	133.49	5.34	0.36	260.21	10.41	0.00	35.28	1.41	118.82	429.0	17.16	
28	28-08-17	201.6	3.16	9.29	0.37	22.27			41.99	115.27	4.61	0.40	259.92	10.40	0.00	35.28	1.41	121.39	410.5	16.42	
29	29-08-17	208.8	3.27	8.50	0.34	23.16			43.43	104.90	4.20	0.44	259.63	10.39	0.00	35.28	1.41	122.87	399.8	15.99	
30	30-08-17	216	3.36	7.85	0.31	24.05			45.01	93.53	3.74	0.48	259.34	10.37	0.00	35.28	1.41	124.49	388.2	15.53	
31	31-08-17	223.2	3.53	6.62	0.26	24.94			47.29	77.11	3.08	0.52	259.06	10.36	0.00	35.28	1.41	126.81	371.4	14.86	
32	01-09-17	230.4	3.64	5.83	0.23	25.83			49.62	60.34	2.41	0.56	258.77	10.35	0.00	35.28	1.41	129.18	354.4	14.18	
33	02-09-17	237.6	3.77	4.90	0.20	26.72			51.56	46.37	1.85	0.60	258.48	10.34	0.00	35.28	1.41	131.16	340.1	13.61	
34	03-09-17	244.8	3.91	3.89	0.16	27.61			53.78	30.38	1.22	0.64	258.19	10.33	0.00	35.28	1.41	133.42	323.9	12.95	
35	04-09-17	252	4.04	2.95	0.12	28.50			55.73	16.34	0.65	0.72	257.62	10.30	0.00	35.28	1.41	135.45	309.2	12.37	
36	05-09-17	259.2	4.16	2.09	0.08	29.39			57.98	0.14	0.01	0.76	257.33	10.29	0.00	35.28	1.41	137.74	292.8	11.71	
37	06-09-17	266.4	4.28	1.22	0.05	30.28			59.84			0.80	257.04	10.28	0.00	35.28	1.41	139.64	279.1	11.16	
38	07-09-17	273.6	4.44	0.07	0.00	31.17			60.92			0.84	256.75	10.27	0.00	35.28	1.41	140.76	271.0	10.84	
39	08-09-17	280.8	4.51			32.06			61.43			0.89	256.39	10.26	0.00	35.28	1.41	141.32	267.0	10.68	
40	09-09-17	288	4.51			32.95			62.38			0.94	256.03	10.24	0.00	35.28	1.41	142.32	259.8	10.39	
Maximum adsorption capacity				24.64 mg/g GAC			348.8 µg/g GAC			356.3 µg/g GAC			> 417.2 µg/g GAC			> 56.5 µg/g GAC				> 1175 µg/g GAC	

Where x is the amount of adsorbate from 7.2 L, x/m is the mass of adsorbate from 7.2 L per unit mass of adsorbent (mg adsorbate/g GAC).

From the above results (Table, 3) we find that, the maximum adsorption capacity of TOC is 24.52 mg/ (g GAC), maximum adsorption capacity of chloroform, is 348 $\mu\text{g}/$ (g GAC), maximum adsorption capacity of bromodichloromethane is 359 $\mu\text{g}/$ (g GAC). The maximum adsorption capacities of dibromochloromethane and bromoform did not reach the maximum at the end of experiment after 40 days, (adsorption capacity of dibromochloromethane is more than 417 $\mu\text{g}/$ (g GAC), and that for bromoform is more than 56 $\mu\text{g}/$ (g GAC). The output of the column was free of bromoform until the end of the experiment after 40 days. This estimation assumes a constant influent concentration of analytes and neglects the influence of competitive adsorption.

The amount of total values of (DBPs-VOCs) is reduced from 178.4 $\mu\text{g}/\text{l}$ (initial concentration before GAC) to 94.25 $\mu\text{g}/\text{l}$ after passing 158.4 L of produced water of South Alamein WTP which is below enough the maximum permissible limit (100 $\mu\text{g}/\text{l}$).

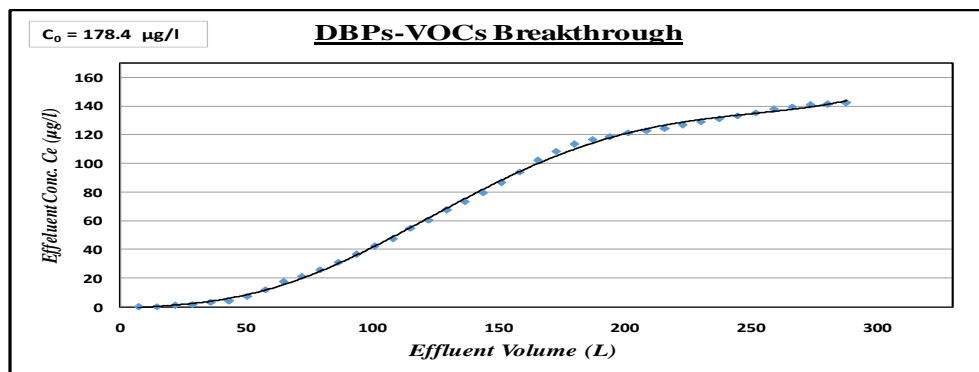


Figure (7): Variation of effluent concentration C_e of (DBPs-VOCs) after passing through GAC glass column at constant contact time 10 min from the produced water of South Alamein WTP with volume during August 2017.

As shown in Figure (7), the concentration of total values of (DBPs-VOCs) measured in the effluent of the glass column (Cout) was near to 0.0 µg/l, then the concentration increases gradually until it reaches a value (about 94 µg/l), which is less than the Egyptian guidelines (100 µg/l). The entire amount of GAC (25 g) should be changed after passing 158.4 L from the produced water of South Alamein WTP, at which the total values of (DBPs-VOCs) is reduced from 178 µg/l to 94 µg/l, at constant temperature, pH and contact time 10 min. (Table, 3).

For DBPs-VOCs (formed during disinfection process), according to table (3), the maximum adsorption capacity of adsorbent GAC to adsorbate (DBPs-VOCs) is 908.64 µg/g (0.90864 g/kg). To reduce the initial concentration C_0 from 178.4 µg/l (above the permissible limit 100 µg/l) to 94 µg/l, about 84.15 µg/l are adsorbed on the adsorbate GAC (0.0815 g/m³) yields 14474 g/day of (DBPs-VOCs), applied to 498.75-m² cross-section of GAC bed. This cross-section, 2.4 m deep, contains 1197 m³ of GAC media. Converting this to weight yields 580545 kg of adsorbent (GAC density = 485 kg/m³). Therefore, the days required to “load” this adsorbent to equilibrium is:

$$\begin{aligned} \text{Days of operation} &= \frac{\text{Total weight of adsorbent kg GAC} \times \text{equilibrium loading}}{\text{Daily load}} \\ \text{Days of operation} &= \frac{(580545 \text{ kg}) (0.90864 \text{ g/kg})}{14474 \text{ g/day}} \\ &= 36 \text{ Days} \end{aligned} \quad [\text{Eq. 1}]$$

The above results of application of the maximum adsorption capacity of examined parameters in South Alamein WTP are summarized in table (4) with respect to coast of GAC duration.

Table (4): Summary of important figures when a GAC bed removal is applied in South Alamein WTP.

For South Alamein WTP	Compounds			
	TOC	CHCl3	CHBrCl2	DBPs- VOCs
Initial concentration C₀	4.45 mg/g	79 µg/g	58 µg/g	178.4 µg/g
Maximum adsorption capacity	23.55 mg/g	150 µg/g	366 µg/g	909µg/g
Days of operation	18.7	14.9	20.7	36
Maximum production	172000 m ³ /day			
GAC Weight	581 Ton			
Price of GAC	About 1000 \$			
GAC Coast/36 Days	581000 \$			
Total GAC Coast/year	5.89 Million \$			
Overhead coast / m³	0.094 \$			

CONCLUSIONS

The study recorded the absence of VOCs contaminant in raw water of both selected sites which indicate that the industrial discharge before Cairo Governorate and along the next branches to arrive the next site over 285 km include (Nile River - Behery main branch - Noubaria canal - El Nasr canal - Elhammam Canal) are not loaded with VOCs contaminants. The average concentrations of VOCs that produced during the treatment process (DBPs-VOCs) from Shubra El-Kheima WTP are within the accepted limits during 2016 (64µg/l) and below the maximum permissible limit (100 µg/l). The average concentrations of VOCs that produced during the treatment process

(DBPs-VOCs) from South Alamein WTP do not comply the Egyptian guidelines during 2016 (120 μ g/l) and higher than the maximum permissible limit (100 μ g/l).

The average concentration of VOCs that produced during the disinfection process with chlorine (DBPs-VOCs), is not comply with the Egyptian guidelines during 2016, (South Alamein booster 132 μ g/l, Sidi Abdel Rahman booster 148 μ g/l , Aldabaa Booster 174 μ g/l , Fuka Booster 201 μ g/l , Ras Elhekma Booster 214 μ g/l and Garawla Booster 224 μ g/l) which is higher than the maximum permissible limit (100 μ g/l).

The increase in VOCs values as we going from South Alamein WTP to the boosters are due to the increase in contact time of treated water with residual chlorine and the extra dose of chlorine in that boosters to compensate the losses that consumed along this distance in reacting with TOC precursor to produce more amount of VOCs .

- GAC could successfully minimize the concentrations of TOC as a main precursor of the produced VOCs from the disinfection process with chlorine and consequently DBPs-VOCs (CHCl₃, CHBrCl₂, CHBr₂Cl and CHBr₃).

-The average consumption of GAC is 581 Ton per 36 days of operation in South Alamein WTP where it produces 172000 m³/day. The average overhead cost of using GAC in South Alamein WTP is 0.094 \$/m³ water.

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رصد ومعالجة المواد العضوية المتطايرة في مياه الشرب

دراسة مقارنة

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المستخلص

تمثل المركبات العضوية المتطايرة في مياه الشرب تأثيرا سلبيا على صحة الإنسان والبيئة وخاصة التي يتم تكوينها أثناء عملية المعالجة بالكلور خلال مراحل المعالجة، وهذه المركبات تصنف على أنها مركبات مسرطنة محتملة للإنسان إذا تجاوزت الحد المسموح به. تمفي هذه الدراسة تقدير المركبات العضوية المتطايرة باستخدام جهاز التحليل الكروماتوجرافي الغازي المزود بمطياف الكتلة باستخدام الطريقة التحليلية (EPA ٥٢٤,٢, 1995). تم عمل دراسة مقارنة شهرية خلال عام ٢٠١٦

للمركبات العضوية المتطايرة في كل من محطتي شبرا الخيمة (على بعد كيلومتر واحد من نهر النيل على ترعة الشراوية) ومحطة مياه جنوب العلمين (على بعد ٢٧٠ كم من نهر النيل على ترعة الحمام بالساحل الشمالى). وقد رصدت هذه الدراسة وجود المركبات العضوية المتطايرة والتي تنتج اثناء استخدام الكلور فى مراحل المعالجة (DBPs-VOCs) ($CHCl_3$ ، $CHCl_2Br$ ، $CHClBr_2$ و $CHBr_3$) وتجاوزت هذه القيم الحد المسموح به في المياه المعالجة لمحطة مياه جنوب العلمين. وقد نجحت هذه الدراسة فى استخدام حبيبات الكربون النشطة فى تقليل قيم المركبات العضوية المتطايرة المتكونة نتيجة استخدام الكلور فى عملية التطهير من (١٧٨ ميكروجرام / لتر) إلى (٩٤ ميكروجرام / لتر). وكان معدل استهلاك حبيبات الكربون النشطة فى حدود (٥٨١ طن) كل (١٧ يوما) وذلك عند تشغيل المحطة على اقصى سعة انتاجية لها (١٧٢٠٠٠ متر مكعب /يوم).