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Original Article

Impact of Raw Water Ammonia on the Surface Water Treatment Processes and Its Removal by Nitrification

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Impact of raw water ammonia on the treated water quality and removal of ammonia from surface water were studied. Raw water ammonia and physicochemical quality of treated water of Saidabad Water Treatment Plant were analyzed for the period of one year (January through December 2006). The monthly averages of maximum (7.55 mg/l) and minimum (0.34 mg/l) ammonia-N level of the raw water were recorded in March and September 2006 respectively. During dry season raw water containing high concentration of ammonia reacted with chlorine at pre-chlorination step of treatment processes and disrupted the total treatment system. It was found from the study that when the concentration of ammonia was high in raw water the aesthetic characters such as turbidity, colour, taste, odour, alkalinity, total dissolved solids (TDS), conductivity, total chlorine etc. of the treated water were changed significantly. Chemical consumption is increased as a result water treatment costs is increased. To mitigate the above problems of the treated water nitrification was used for the removal of ammonia from raw water. Ammonia removal rate was monitored with some other water quality parameters during the study. In the nitrification process ammonia was removed from raw water very effectively, *i.e.*, maximum about 98% raw water ammonia was removed during the study. Additionally other water quality factors were improved significantly.

Keywords: Raw water, Treated water, Raw water ammonia, Water quality, Nitrification

Introduction

In many developing countries, safe water is enjoyed by a small proportion of the population. It was estimated in 1988 that the health of between 9-22 million children of less than five years old are compromised each year in developing countries because of lack of water, inadequate sanitary facilities and waterborne diseases[1].

In Dhaka City, Dhaka Water Supply and Sewerage Authority (DWASA) supply drinking water and provides sanitation services since 1963 to the city dwellers. About 10 million people depend on the supply of drinking water and sanitation services provided by DWASA. At present DWASA is dependent more on the surface water than the under ground water because of over extraction of ground water[2]. Every year 2-3 m water level is going down. In this context, Saidabad Water Treatment Plant (SWTP) was established with the capacity of 225 MLD and went into operation on July 27, 2002. The Sitalakheya River near Dhaka city is the source of raw water for the SWTP (Figure 1). Different treatment processes like pre-chlorination, coagulation, filtration, disinfection, pH correction are used at SWTP to make the water potable as well as wholesome to the consumers.

Figure 1. *Raw water source and its transmission network from Lakheya River through DND canal to SWTP.*

Ammonia is one of the important constituents of domestic wastewater and concentrations commonly range from 10 to 50 mg total ammonia-N/l, but might be as high as 200 mg total ammonia-N/l in domestic wastewater in arid and semiarid countries or industrial wastewater[3]. The condition of water in the peripheral river systems of Dhaka City like Balu-Lakheya River system, Dhaleswari-Kaliganga River system and Bangshi-Turag-Buriganga River system has created great concern due to their massive deterioration in quality because of insidious pollution

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by industries and indiscriminate discharge of sewage[4]. Insufficient treatment of domestic sewage is one of the major reasons for the degradation of water environment[5]. Excessive ammonia concentration and algae in Sitalakhya River are making difficulty the treatment system for raw water at SWTP particularly during the period from November to April[6]. It was found in a study that the monthly maximum averages of ammonia-N level for the raw water was 7.06 mg/l in March 2004[7].

Biological water purification is an excellent way to lower the organic load of dissolved organic compounds. Microorganisms mainly do the decomposition of these compounds. In the natural way nitrogen in organic matter is mineralized to ammonia. Ammonia is toxic to most organisms in elevated concentrations. In the nitrification process ammonia can be converted to nitrate. Nitrate is not known to have toxic properties even at high concentration in compare to the ammonia[8]. Worldwide researchers have been working on the development of cost-effective methods for the purification of natural waters from anthropogenic contaminants. Chlorine demand of ammonia-laden groundwater was reduced after nitrification[9]. Nitrification was found to lower treatment costs and also to reduce the formation of trihalomethanes. It was reported that nitrification of ammonia containing ground water resulted in "biologically stable" water that didn't support bacterial growth in the distribution system[10].

There is no detailed study about the impact of raw water ammonia on the treated water quality of SWTP since its operation (July 2002) and also there is no study on the removal of ammonia from raw water effectively. The aims of the present study were to measure the impact of raw water ammonia on the treated water quality, water treatment system, and to find out its removal by nitrification process as an environmentally friendly treatment system.

Materials and Methods

Collection of raw and treated water samples

The study was carried out during the period of January through December 2006. Water samples, from inlet point (raw water from the Sitalakheya River) and outlet point (treated water) of the Saidabad Water Treatment Plant (SWTP), Dhaka were collected in sterile glass bottles for weekly physicochemical analyses. Samples, kept at 4^oC, were analysed without much delay to avoid any alteration.

Preparation of the bio-filter

A PVC column with internal diameter 50 mm and length about 3.5 m was set in the laboratory (Figure 2). We took the raw water before the injection of pre-chlorination and fed the PVC column containing biolite media (expanded clay) and nitrifying bacteria (provided by the Degremont, a French water treatment specialist company). NH_4Cl (Merck, Germany) solution was connected to the raw water to raise the ammonia level in feed water. Height of column, *i.e.*, media 2.2-3.0 m, filtration velocity 20-30 l/h of raw water flow was maintained. An aerator was connected with the bio-filter to raise dissolved oxygen (DO) of feed water. Aeration ratio: air/water: 1.5-2 (40-45 l/h of air process) because 3-4 mg/l of oxygen is needed for the removal of 1 mg/l of NH_4^+. After optimizing the growth of nitrifying bacteria (3-4 days) we collected water sample from the outlet of bio-filters and subsequently performed the different physicochemical analysis to monitor the removal of ammonia from raw water.

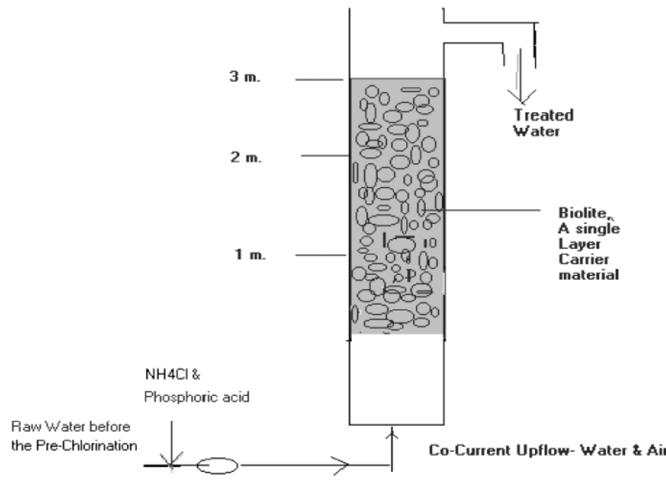

Figure 2. *Biofilter for the nitrification process*.

Physicochemical analysis

Turbidity of the samples was determined with a turbidity meter (Model: WTW, Turb-550, USA). pH values of the samples were determined with a digital pH meter (Model: sensION2, Hach, USA). Electrical conductivity (EC) and total dissolved solids (TDS) were measured with a conductivity meter (Model: sensION7 Hach, USA). Dissolved oxygen (DO) of the samples was conducted by a DO meter (Model: sensION8, Hach, USA). Samples were filtered through a 0.45 μm pore size membrane filter (Sartorius, Minisart, Germany) and then the colour was recorded by a spectrophotometer (Model: DR/2500, Odyssey, Hach, USA) according to the standard methods and procedures[11]. Total alkalinity was determined using standard titrimetric methods[12-13]. Ammonia-N, total chlorine, nitrate-N, phosphate (orthophosphate) and iron were determined spectrophotometrically (Model: DR/2500, Odyssey, Hach, USA) according to the standard methods and procedures[11].

Results and Discussion

Physicochemical factors are very important aspects of the sanitary quality of water. Month wise values of physicochemical factors of the treated and raw water of SWTP are given in (Table 1). The maximum and minimum values of ammonia-N for the raw water were (7.55 mg/l and 0.34 mg/l in March and September 2006 respectively. It was found that the ammonia concentration increased remarkably from November to March and dropped down in April. The decreasing trend of raw water ammonia remained up to September-October and again the concentration of ammonia

Table 1. *Values of the physicochemical parameters of raw water and treated water of SWTP in the year 2006*

Month*	Raw water	Treated water						
	NH_3-N (mg/l)	Total Cl_2 (mg/l)	pH	Turbidity (NTU)	Colour (TCU)	EC (µS/cm)	TDS (mg/l)	TA (mg/l as $CaCO_3$)
January	2.87	3.89	7.12	0.56	10	344	180	145
February	6.89	3.90	7.24	2.74	14	500	248	185
March	7.55	4.05	7.34	3.53	16	703	334	206
April	2.81	3.13	7.23	1.16	5	632	295	157
May	1.66	2.64	7.13	0.56	5	443	198	122
June	0.68	0.98	6.83	0.55	3	157	72	31
July	0.46	0.42	7.01	0.21	3	158	71	41
August	0.45	0.37	6.84	0.19	1	176	83	46
September	0.34	0.43	6.89	0.20	1	178	80	58
October	0.50	0.38	6.78	0.20	1	172	77	50
November	1.38	3.07	6.92	0.29	3	291	141	101
December	3.40	4.44	7.10	0.80	4	386	192	147

*Monthly average values are presented. NH_3-N = Ammonia-nitrogen; NTU = Nephelometric turbidity unit; TCU= True colour unit; EC = Electrical conductivity; TDS = Total dissolved solids; TA = Total alkalinity.

begun to increase from November. Whereas in July-October raw water ammonia level was found very low and after chlorination into the raw water no ammonia or very little ammonia was detected at the same time in treated water. It was observed that in the dry season, *i.e.*, December to April the NH_3 concentration remained so high as compared with the WHO guide line value and Bangladesh standard of 1.5 mg/l and 0.5 mg/l[14-15]. The addition of chlorine (Cl_2) to raw water containing high ammonia (NH_3) during the treatment is formed chloramines[16]. The chloramines are known as combined chlorine and is less active than hypochlorous acid (residual chlorine), *i.e.*, one twentieth the power of hypochorous acid[17]. Combined chlorine is not so active against the algae proliferation and ultimately huge amount of algae is formed in the clarified water as well as settle on the different parts of the clarifier and filtration systems[18]. The combined chlorine, *i.e*., total chlorine concentration was high all over the period from January to April and also in December. The maximum (5.05 mg/l) and minimum (0.37 mg/l) values of total chlorine of treated water were found in March and August 2006 respectively.

Maximum pH value of treated water was recorded 7.34 in March and minimum value recorded 6.78 in October which followed the WHO Guidelines values of 6.5 to 8.5[14]. It was observed that when raw water is highly polluted, ammonia concentration is remarkably elevated in raw water pH of the treated water was recorded high. Microbiological and chemical parameters of the water are markedly influenced by pH. Small changes in pH may be the cause of significant changes in other qualities like solubility of iron, manganese, copper, calcium, and other metals[19].

A good variation of raw water turbidity was found from June to October or until the end of the rainy season, and was relatively stable and low during the winter season, *i.e.*, in the dry season. The treated water turbidity was maintained less than 0.30 nephelometric turbidity unit (NTU) during July to December and which is very well under the WHO guideline value 5 NTU but in dry season it is increased very high, *i.e.*, January to April 0.56-3.53 NTU respectively. Turbidity in water was due to the presence of suspended colloidal particles such as clay, silt, finely divided organic matter, plankton and other microscopic organisms.

The treated water colour was found low and well under the WHO Guideline value of 15 true colour unit (TCU) for most of the time to the exception of the period of mid February to the end of the April. The maximum value of the treated water colour was found 15 TCU in March 2006 and minimum of 2 TCU in July to October. The total alkalinity (TA), conductivity and the total dissolved solids (TDS) were somewhat stable in June to October and then followed a continuous and sharp increase up to March.

From April the above three mentioned parameters were also followed a nearly identical decreasing trend. The monthly maximum and minimum alkalinity were recorded for the treated water 206 mg/l as $CaCO_3$ in March and 31 mg/l as $CaCO_3$ in June 2006 respectively (Table 1). The maximum and minimum values of TDS in treated water were 334 mg/l in March 2005 and 71 mg/l in June 2006 respectively (Table 1), whereas maximum and minimum values of electrical conductivity (EC) in treated water were 703 µS/cm (in March) and 158 µS/cm (in June 2006) respectively (Table 1).

Alum ($AlSO_4.18H_2O$) was used as coagulant for the separation of non-settleable particles from the raw water and chlorine was used for disinfection purposes and also to oxidize the organic and inorganic materials present in the raw water. Seasonal variations of chemical doses for raw water treatment in SWTP are shown in Figure 3. It was revealed that alum consumption was remarkably high during February to April (30.14-35.29) mg/l and also chlorine consumption (7.22-9.07) mg/l was remarkably high at the same period. But August through January the both chemicals consumption was enough less. Usually more turbid water requires more coagulant but interestingly January to April raw water turbidity remain very low with high ammonia concentration and at that time chemical consumption was increased remarkably. As a result, water treatment cost is increased.

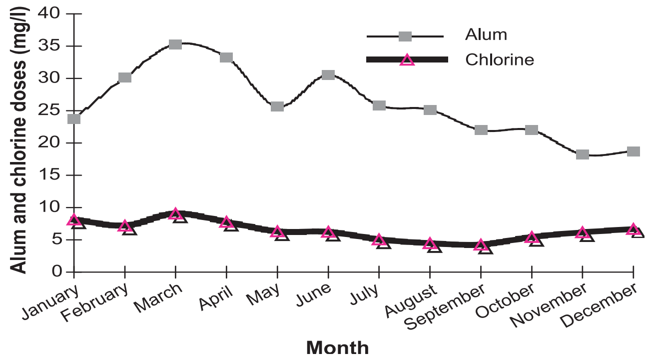

Figure 3. *Monthly averages of alum ($AlSO_4.18H_2O$) and chlorine doses used for the treatment of raw water in 2006*.

Biological nitrification is more environmentally friendly and cost effective than any other chemical methods of ammonia removal[20]. Values of physicochemical factors of the raw and bio-filtered water are given in Table 2. Figure 4 depicted the concentration of ammonia-N of feed and bio-filtered water during the nitrification process. The range of ammonia-N of the feed water to bio-filter was (10.5-8.3) mg/l. On the other hand, after nitrification ammonia-N of feed water was oxidized successfully and reduced to a range of 0.12-2.68 mg/l. A very good removal rate of ammonia-N from the raw water by nitrifying bacteria was clearly observed in the study as well as indicated the study as natural treatment way of ammonia removal from surface water. Nitrifying bacteria in the nitrification process detoxify ammonia in two steps. First, *Nitrosomonas* spp. converts toxic ammonia to nitrite, in the second step; nitrite is converted to nitrate by *Nitrobacter* spp.[21].

Concentration of nitrate-N of feed water was 2.0-3.5 mg/l but there was a sharp increase of nitrate-N after nitrification. 5.9-10.4 mg/l of nitrate-N in bio-filtered water was detected, which was indicating the occurrence of nitrification. In the nitrification process, ammonia is oxidized and subsequently forms nitrite and the end product is nitrate. Occurrence of nitrification can be conformed by monitoring for nitrate or nitrite[21].But in the water treatment processes, the nitrate concentration does not create any problem with chlorine which is injected into the raw water at the time of treatment. On the other hand, 50 mg/l of nitrate-N is acceptable for drinking water[14].

The pH values observed for feed water from 7.24-7.43. At the same time pH of outlet water of bio-filter observed from 6.8-7.15. Feed water alkalinity was 160-190 mg/l as $CaCO_3$. Where as alkalinity of the bio-filtered water was reduced remarkably and varied from 90-120 mg/l as $CaCO_3$. A decreasing trend of pH and alkalinity values was observed. Nitrification is often indirectly identified by drop in pH and alkalinity[22]. Many factors contribute to the viability of nitrifying bacteria and as a result, nitrification episodes have been observed at pH level ranging from 6.6 to 9.7[23].

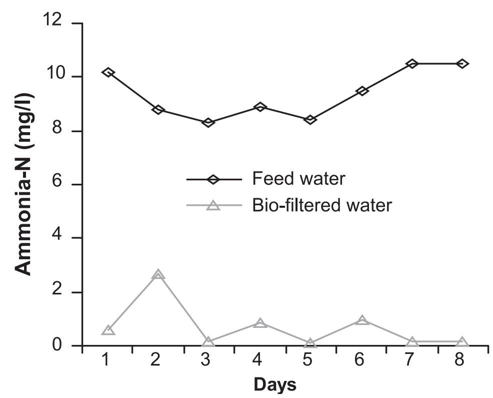

Figure 4. *Removal of ammonia from surface water by nitrification*.

Table 2. *Physicochemical quality parameters of feed water and outlet water of a nitrification pilot plant*

Date (April 2004)	Quantity of water (l/h)	Quantity of air (l/)h	Water temperature (°C)	Air temperature (°C)	NO_3-N (mg/l)	PO_4 (mg/l)	Fe (mg/l)	pH	TA (mg/l as $CaCO_3$)	Turbidity (NTU)	O_2 (mg/l)
Inlet raw water											
19	20	40	30	29	2.0	1.70	0.11	7.43	180	20.4	2.97
20	20	40	28	31	3.3	1.65	0.12	7.24	190	16.1	2.93
22	20	40	29	30	2.8	1.6	0.08	7.34	190	30.4	2.52
25	20	40	30	30	2.6	1.5	0.12	7.37	180	20.5	2.77
26	30	45	29	30	2.2	1.45	0.10	7.31	170	19.7	
27	30	45	29	30	2.60	1.40	0.14	7.28	160	19.2	2.86
28	30	45	29	30	3.5	1.50	0.18	7.25	170	23.8	
29	30	45	30	30	3.4	1.2	0.2	7.26	160	32.6	2.94
Outlet water											
19					6.0	1.50	0.06	7.12	110	10.3	4.48
20					5.9	1.40	0.05	6.80	115	8.5	4.50
22					7.0	1.54	0.04	7.15	120	10.8	5.03
25					7.8	1.20	0.07	7.15	120	12.3	4.98
26					8.0	1.20	0.05	7.12	105	7.52	4.50
27					7.9	1.15	0.06	6.98	95	13.3	4.38
28					10.4	1.30	0.08	7.04	100	9.2	4.46
29					7.4	0.84	0.09	7.05	90	9.2	4.53

NO_3-N = Nitrate-nitrogen; PO_4 = Phosphate; Fe = Iron; TA = Total alkalinity; NTU = Nephelometric turbidity unit.

A sharp dropdown of turbidity was observed during the nitrification process. The range of turbidity of feed water was 32.6-16.1 NTU and the turbidity of the bio-filtered water was found to be 13.3-7.52 NTU. Temperature is a very important factor for nitrifying bacteria. Temperature of the feed water was remained almost steady state during the study period from 28-30°C, which is correlated to the optimum temperature (25-30°C) for nitrifying bacteria. Dissolved oxygen (DO) is one of the important factors for nitrification. It is a limiting factor for the activity of nitrifying bacteria. DO of the feed water was 2.97-2.52 mg/l, whereas DO of the bio-filtered water fluctuated from 4.38-5.03 mg/l during the study period. An aerator was connected with the bio-filter as a result DO of outlet water was increased.

There was also a sharp dropdown of the iron of bio-filtered water. In nitrification process iron also reduced potentially. Feed water contained 0.08-0.20 mg/l iron but after nitrification bio-filtered water showed trace amount of iron, *i.e.*, 0.04-0.09 mg/l. Normally, nitrifying bacteria need phosphate for their good functioning. In this situation feed water contained sufficient amount of phosphate, *i.e.*, 1.2-1.70 mg/l, which was helpful for nitrification process. Phosphate concentration of the outlet water was found from 0.84-1.54 mg/l.

Considering the impact of raw water ammonia on the physicochemical factors of treated water of Saidabad Water Treatment Plant (SWTP), it was obvious that some critical problems arise when raw water contained high concentration of ammonia in dry season. Raw water containing high NH_3 reacts with chlorine, which is injecting as prechlorination step to the raw water and may subsequently form chloramine compounds, *i.e.*, combined chlorine. Combined chlorine is not so active against the algae proliferation as a result immense amount of algae develops in the clarified water as well as different parts of the clarifier and filtration systems. On the other hand, organic and inorganic matters of raw water are not oxidized sufficiently. Ultimately the total treatment processes lost its efficiency in the SWTP during the dry season. High concentration of ammonia in raw water might influenced the aesthetic characters like pH, turbidity, colour, TDS, EC, total alkalinity, total Cl_2, taste, odour etc. of the treated water. Chemical consumption was increased for the raw water treatment as well as costing of the water treatment was raised remarkably. To remove ammonia from raw surface water nitrification process was used. Nitrification is a natural process by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite and then to an end product nitrate. It was observed that nitrification reduced the ammonia load from raw water 69.55-98.57% in this study and indicated clearly that it is a good way of ammonia removal from surface water. Examining the physicochemical parameters of bio-filtered water, a significant improvement was found in the bio-filtered water which is very helpful for effective water treatment.

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