Optimization of Chlorine Dose at Saidabad Water Treatment Plant

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***Abstract*— The Saidabad Water Treatment Plant (SWTP) serves as a major drinking source for the people of Dhaka. The treatment process employed at the treatment plant involve pre-chlorination and pH adjustment of the raw water, followed by coagulation with alum in a clarifier; filtration and finally post-chlorination and pH adjustment of the water before its introduction in the distribution system. The raw and treated water quality at SWTP from July of 2003 to December of 2006 has been assessed. Especially parameters related to the disinfection process have been assessed and these include pH, Ammonia, Free chlorine and Total chlorine. The water quality at SWTP shows clear seasonal variation. The major water quality problem at SWTP is very high concentration of ammonia particularly during the dry season (exceeding 10 mg/l). The chlorine applied for chlorination is converted to chloramines in the presence of high concentration of ammonia, especially in the dry season. Higher chlorine doses (6.5 mg/l) are applied during the dry season (July to November) to take care of high ammonia concentration), while lower doses (4 mg/l) are applied during the wet season (December to June). The total chlorine concentration in the treated water follows the trend of applied chlorine doses. The total chlorine concentration was low (0.37-0.67 mg/l) during wet period and high (3.00-6.05 mg/l) during dry period. It appears that the present practice of chlorination at the SWTP during both dry and wet seasons may lead to the formation of undesirable chloramines (e.g., dichloramine and nitrogen trichloride), which are not effective disinfectant and may give rise to taste and odor problem, while at the same time increases disinfection costs.**

In this study, optimum chlorine dose has been estimated by considering Chlorine to Ammonia concentration ratios. During dry season, high concentration of ammonia in water does not allow use of "break point chlorination". On the other hand, at chlorine to ammonia concentration ratio (expressed in mg/l) exceeding 4.2, undesirable chloramines are formed. Hence during dry season, the chlorine dose should be such that chlorine to ammonia concentration ratio remains around 4.2. During wet season, the ammonia concentration in raw water is rather low and hence it would be possible to implement "break point chlorination", so that some free chlorine (e.g., 0.5 mg/l) is present in the treated water. At present, the estimated quantity of chlorine used during the dry season and wet season are about 261 tons and 111 tons, respectively. Whereas, if the optimization recommended in the present study is followed, then corresponding chlorine requirement would be about 96 tons and 188 tons, respectively. If chlorine dose is applied taking into consideration the ammonia concentration in raw water at the SWTP, then it would not only improve effectiveness of disinfection, but would also reduce the cost of chlorination significantly.

Keywords*— *chlorine dose; water treatment plant; breakpoint chlorination;

I. INTRODUCTION

To meet the increasing demand of potable water in Dhaka City and in an effort to reduce the overwhelming dependence on groundwater resources for water supply, DWASA commissioned the surface water treatment plant at Saidabad in June/July, 2002. The SWTP draws water through an intake structure located at Sarulia (near Demra ghat), on the Sitalakhya River, about one-kilometer south of the confluence with the Balu River. Currently, in its first phase, the plant treats 225 million liters of water per day. After completion of the proposed second and third phases, the capacity of the treatment plant would be raised to 450 and 900 million liters per day, respectively. The treatment processes employed at the treatment plant involve:

1) Pre-chlorination and pH adjustment (with lime, if necessary) of the raw water, followed by coagulation with alum (aluminum sulfate) in a clarifier;
2) Filtration of the water coming from the clarifier; and finally
3) Post-chlorination and pH-adjustment (if necessary) of the water before its introduction in the distribution system.

The water quality of all the five rivers around Dhaka, including the Balu and the Sitalakhya, is deteriorating rapidly due to pollution from industrial and municipal sources, and the situation turns particularly alarming during the dry season. Due to the deteriorating quality of the raw water coming through its intake structure at Sarulia, the Saidabad water treatment plant is facing significant problems in treating water during the dry season. The main concern for the Saidabad water treatment plant during the dry season is the high concentration of ammonia and algae in the intake water. High ammonia interferes with the treatment processes in a number of ways, including lowering algae removal efficiency and increasing the chlorine dose requirement. Increasing chlorine dose may result in formation of trihalomethanes. Although, ammonia does not have any particular toxic effect, its presence in the treated water would cause taste and odor problems. Chlorine reacts with ammonia forming chloramines; the major chloramines species to be formed depend primarily on chlorine to ammonia ratio. For examples monochloramine (NH_2Cl), which forms at relatively low Cl_2 to ammonia ratio has significant disinfection capability, whereas dichloramine ($NHCl_2$) which form at higher Cl_2 to ammonia ratio (8.4) also has disinfectory power but may give rise to taste and odor problem. Nitrogen trichloride which forms at even higher Cl_2 to ammonia ratio (12.5) is not effective as a disinfectant. On the other hand, if free chlorine is available in water, it may result in the formation of trichloromithanes as a result of reaction with organic matter and bromide. Thus chlorine dose at the SWTP should be optimized keeping in mind these important issues. This paper provides an assessment of raw and treated water quality at the SWTP focusing on the chlorination issue. It assesses the present chlorination practice at the SWTP and presents a methodology for optimization of chlorine dose.

II. METHODOLOGY AND DATA COLLECTION

Data used in this study have been collected from Saidabad Water Treatment Plant (SWTP).These data represent daily water control analysis – from July 2003 to December 2006. The data obtained from the Saidabad Water Treatment Plant have been analyzed. Especially concentration of ammonia, total and free chlorine in raw and treated water at SWTP have been analyzed. For optimization of chlorine dose chlorine and ammonia concentration ratios have been used.

III. WATER QUALITY OF SWTP

Saidabad Water Treatment Plant (SWTP) is a surface water treatment plant. The Sitalakhya River is the source of the raw water for the plant. Different Treatment processes like prechlorination, coagulation, filtration, disinfection And pH correction is used at SWTP. We have collected data of Ammonia, TDS, Free and total chlorine of both raw and treated water and assessed the water quality.

A) Ammonia

Figure 3.1shows the variation of Ammonia with time (days) in raw and treated water of SWTP during the periods July 2003 to December 2006. Ammonia concentration in raw water shows a sinusoidal pattern, very high concentration (sometimes exceeding 10 mg/l) in the dry season (15February-April) and relatively low concentration during the wet season (May-14February). In raw water the ammonia was low (0.16-0.6 mg/l) during July through November, moderate (0.1-4.05 mg/l) in the months of May, June and December, and high (1 - 10.45 mg/l) during January through April. In treated water the ammonium value was low (0.0-1.34mg/l) during May through November, moderate (0-3.2 mg/l) in December, and high (0.37-9.45mg/l) during January through April. The upper limit for NH_3 concentration in potable water, according to WHO (2004) and Bangladesh Standard (1997) are 1.5 mg/l and 0.5 mg/l, respectively.

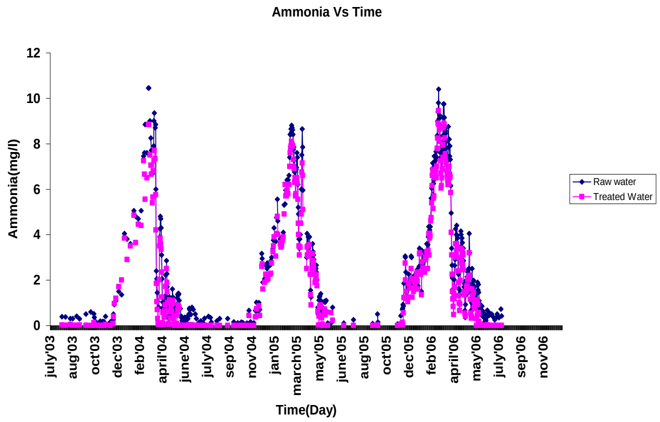

Fig. 1. Ammonia concentrations in raw and treated water at SWTP

However, the level of ammonia-N in treated water was little elevated in the dry months that coincided with high level of ammonium contamination in the water of SWTP. High concentration of ammonia in raw water coincided with increased load of coliforms, and that might also influenced the aesthetic properties like turbidity, colour, taste, odour, etc. of the treated water. The high concentration is mainly due to pollution of water by domestic and industrial discharges. The low concentration during the wet season is due to dilution by rain water / upstream fresh water. Ammonia concentration in treated water follows the same pattern as that in raw water. Lack of sufficient reduction of ammonia concentration in the treated water implies that chlorination changes the chemical form of dissolved ammonia – from free ammonia (NH_3, NH_4^+) to chloramines, without changing the total ammonia concentration.

The pre-chlorination of the raw water at the Saidabad water treatment plant helps in the elimination of algae (besides reducing the number of fecal bacteria and pathogens) during subsequent coagulation and filtration processes. Chlorine disrupts the air sac in algae that allows it float in water. However, if ammonia concentration is high, it would consume the added chlorine forming chloramines (Eq. 1-3) and no free chlorine would be available for elimination of algae.

$$NH_3 + HOCl = NH_2Cl + H_2O \quad (1)$$

$$NH_2Cl + HOCl = NHCl_2 + H_2O \quad (2)$$

$$NHCl_2 + HOCl = NCl_3 + H_2O \quad (3)$$

Theoretically, it would require 3 moles of chlorine for complete conversion of ammonia to nitrogen trichloride (trichloramine), and 4 moles for the complete oxidation to nitrate (Eq. 4-5). Thus, about 8 mg/l of chlorine is required to oxidize 1 mg/l of ammonia.

$$3\,Cl_2 + 2NH_3 = N_2\,(g) + 6H^+ + 6Cl^- \quad (4)$$

$$4\,Cl_2 + NH_3 = NO_3^- + 9H^+ + 8Cl^- \quad (5)$$

Thus if the ammonia concentration reaches 10 mg/l, a level it approached during the dry season of 2004, the chlorine requirement would be about 80 mg/l. The resulting problems include:

- Increase in treatment cost
- Poor removal of algae
- Probable formation of unwanted disinfection byproducts, particularly chlorinated organics including trihalomethanes (THM) (as a result of reaction of chlorine with dissolved organic matter)
- Excess ammonia/chloramines in the treated water.

In a recent study (Khan, 2008), ammonia concentration of raw and treated water at the SWTP was assessed. Khan (2008) collected water from 5 different locations which included: raw water, water after alum coagulation, water before filtration, water after filtration, and treated water after post chlorination.

Fig 2 shows the variation of total Ammonia concentration at the SWTP during the monitoring period. Total Ammonia concentration of water did not change significantly within the treatment plant and were comparable to the total Ammonia concentrations of the water samples at the inlet pit. Mean Ammonia concentration within the SWTP (i.e., SWTP-1 to 3) varied from 5.80 mg/L on 31 January 2007 to 10.14 mg/L on 13 March 2007. In all cases, Ammonia concentration in treated water was slightly lower than that in raw water. Ammonia concentrations of the treated water samples (after post chlorination) varied from 5.58 mg/L on 31 January 2007 to 9.75 mg/L on 13 March 2007.

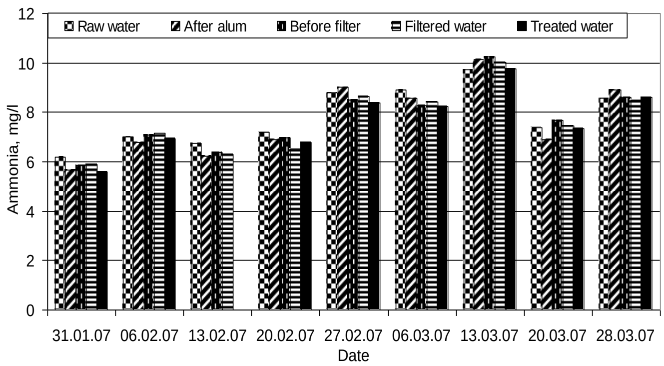

Fig. 2. Variation of Ammonia concentration of water at the SWTP (Source: Khan 2008)

B) Free Chlorine

Fig 3 shows the variation of TDS with time (days) in raw and treated water of SWTP during the period from July 2003 to December 2006. Chlorine in clarified water comes from the chlorine added during pre-chlorination. Then additional chlorine is added in the clarified water (post-chlorination). Most of the chlorine exists as combined chlorine and only a small fraction exists as free chlorine.

The level of free chlorine of the treated water was uniform all over the year, which varied between 0.21 (in December) and 0.51mg/l (in June).

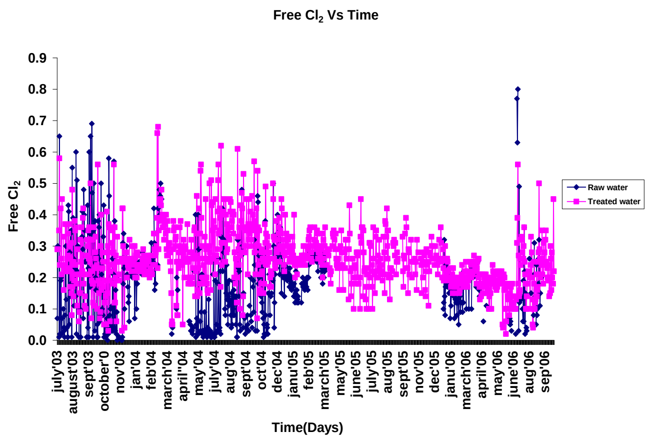

Fig. 3. Free Chlorine vs. Time (day)

C) Total Chorine

Fig 4 shows the variation of total chlorine with time (days) in raw and treated water of SWTP during the period from July 2003 to December 2006. Only limited data is available for total chlorine concentration in raw water.

The total chlorine concentration was low (0.37-0.67/l) during July through November, and high (3.00-6.05) during December through May. The total chlorine concentration follows the trend of applied chlorine doses. Higher chlorine doses (6.5 mg/l) are applied during the dry season (to take care of high ammonia concentration), while lower doses are applied during the wet season (4 mg/l). So values of total chlorine are much higher during the dry season.

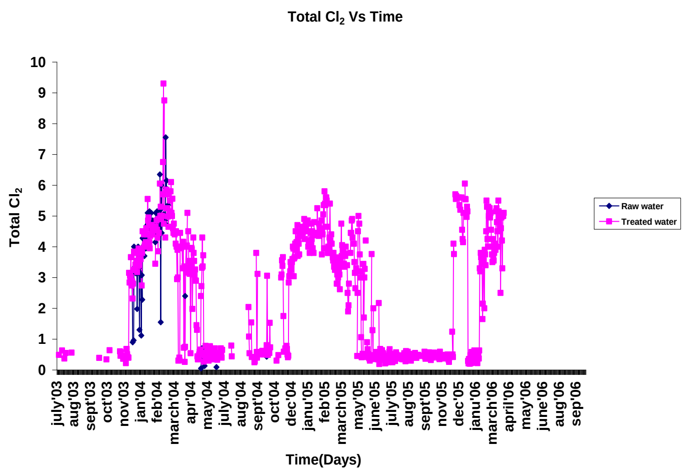

Fig. 4.Total Chlorine vs. Time (day)

IV. OPTIMIZATION OF CHOLORINE DOSE

For optimization of chlorine dose, the formation of different chloramines species formed at different Cl_2 to ammonia ratio has been considered. Table I shows the chlorine species formed at different Cl_2 to ammonia ratio. For optimization of chlorine dose chlorine dose was fixed at a value depending on ammonia concentration of raw water such that it would promote formation of only monochloramine (and not dichloramine or nitrogen trichloride).

TABLE I. Chlorine To Ammonia Ratio For Formation Of Different Chloramines

Species	Cl_2/NH_3
Monochloramine (NH_2Cl)	4.2
Dichloramine ($NHCl_2$)	8.4
Nitrogen Trichloride(Ncl_3)	12.5
Free Residual reaction	9

V. PRESENT PRACTICE OF CHOLORINATION AT SWTP AND PROBLEMS

A) Dry Season

Over most of the dry seasons (From 15 February to April 30) the concentration of Ammonia (in mg/L) present in raw water is higher at the SWTP the chlorine dose used in dry season at SWTP is about 6.5 mg/L and this dose is kept fixed. Fig 1 shows variation of ammonia concentration and chlorine dose for dry seasons of 2004.

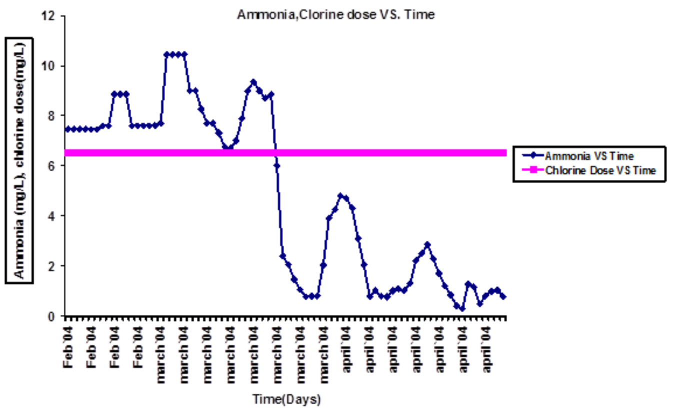

Fig. 5. Ammonia concentration in raw water, Chlorine dose vs. Time (Days) during dry season at SWTP

From the Fig.5 we can see the ammonia concentration varies significantly during dry season. The maximum ammonia concentration is 10.45mg/L and the minimum ammonia concentration is 0.29 mg/L. But chlorine dose applied for pre-chlorination during the dry season is kept at a fixed value of around 6.5 mg/l. As a result Cl_2 to ammonia ratio varies over a wide range, often exceeding values that would promote considerable chloramines (e.g., dichloramines and nitrogen trichloride), which at the same time increases cost of chlorination. Figure 3.8 shows chlorine to ammonia ratio at the SWTP during the dry season of 2004.

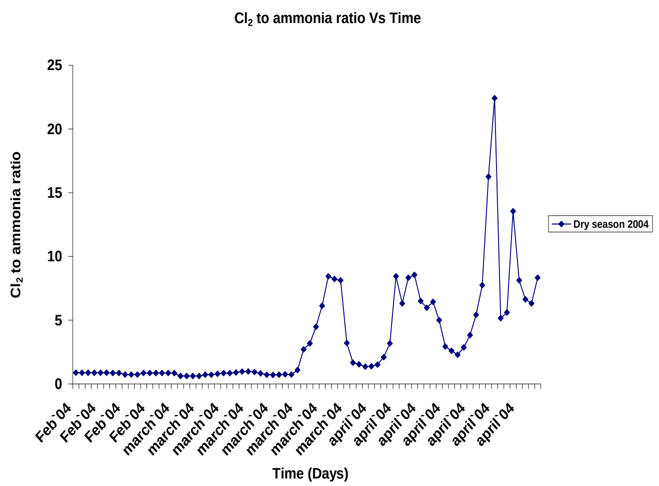

Fig. 6. Ratio of Cl_2 to ammonia vs. Time during dry season of 2004

B) Wet Season

At wet seasons the concentration of ammonia (mg/L) is much less than that of the dry season. For pre chlorination a fixed dose of about 4 mg/L is used at SWTP during the wet season.

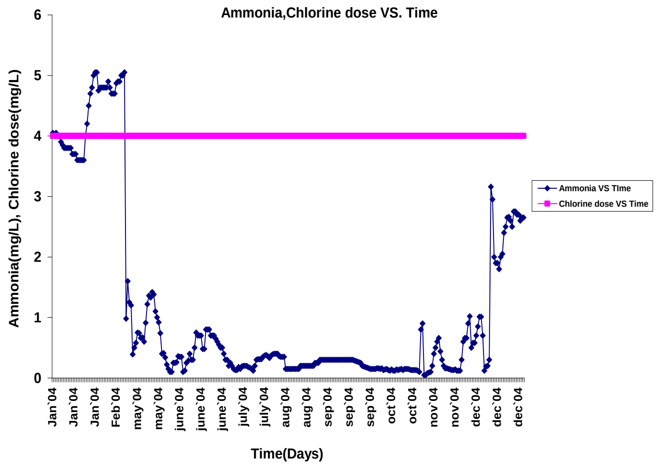

Fig. 7. Ammonia concentration in raw water chlorine dose vs. Time during wet season at SWTP

Fig.7 shows ammonia concentration in raw water and chlorine dose during the wet season. The maximum ammonia concentration in wet season is 5.05 mg/L and the minimum concentration of ammonia is .05 mg/L. As ammonia concentration is very low in wet season, the chlorine dose of 4 mg/L results in chlorine to ammonia ratio that would promote formation of dichloramines and nitrogen trichloride, which is not desirable. Lowering of chlorine dose would not only improve effectiveness of chlorination but would also reduce cost significantly. Fig. 8 shows chlorine to ammonia ratio at the SWTP during the wet season of 2004.

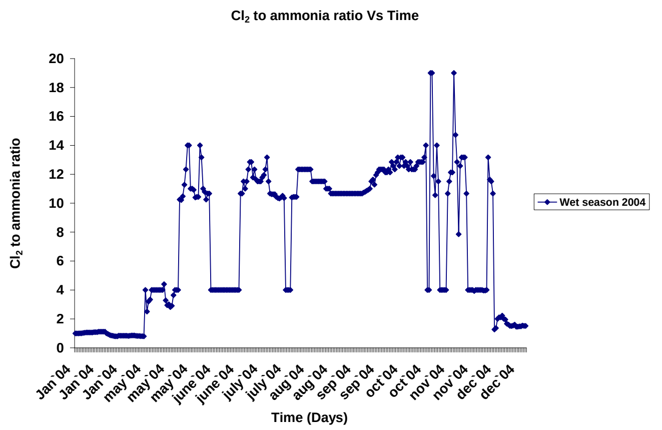

Fig. 8. Ratio of Cl_2 to ammonia during wet season.

VI. OPTIMIZATION OF CL_2 DOSE CONSIDERING AMMONIA CONCENTRATION

In this study optimum chlorine dose has been determined by considering Chlorine to Ammonia Concentration ratios. Various species of chloramines are produced at various ratios. Chlorine dose required for NH_3-Cl_2 reaction are given in Table 2. Among the chloramines species monochloramine is the most effective. Dichloramine also has disinfection capacity but creates taste and odor problem; while nitrogen chloride is not effective as disinfectant. Hence in determining optimum chlorine dose, Cl_2 to ammonia ratio was kept at or below 4.2.

TABLE 2. REACTIONS OF FORMING CHLORAMINES SPECIES

Reaction	Ratio
NH3+Cl2=NH2Cl +H+ +Cl-	4.2
NH3+2Cl2=NHCl2 +2H+ +2Cl-	8.4
NH3+3Cl3=NCl3 +3H+ +3Cl-	12.5

A) Chlorine dose optimization during dry season

We know that at higher Cl_2 to ammonia ratio, dichoramine and nitrogen trichloride species are formed. Monochloramine is formed at lower ratio of 4.2. That is why,we have tried to keep the chlorine to ammonia ratio within 4.2 or below 4.2 so that monochloramines can always be formed. Fig. 4 shows ammonia concentration and optimized Chlorine dose vary for dry season of 2004.

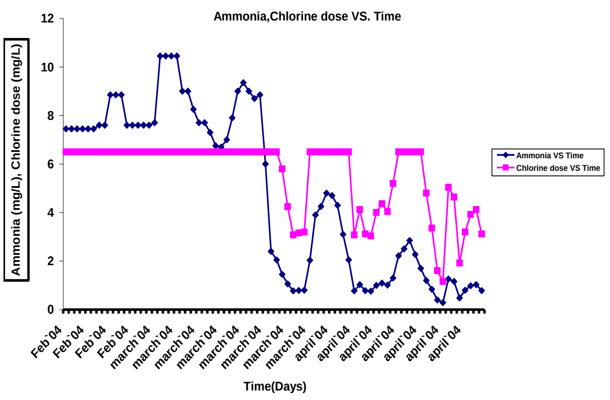

Fig. 9. Ammonia concentration & Optimized Chlorine dose vs. Time (Days) for dry season.

B) Chlorine dose optimization during wet season

In wet season present practice of chlorination makes a very high ratio of Chlorine to Ammonia concentration. The ratio is such that dichloramine could be formed and even free chlorine could be available. The drinking water standard for free residual chlorine is 0.5 mg/L, while concentration higher than this value is present in water (see Fig 3and 4) So present practice of chlorination gives wastage of chlorine which is very uneconomical.

So at wet seasons it will be better to use a ratio at which breakpoint chlorination occurs. When chlorine to ammonia ratio is about 9, the breakpoint chlorination occurs which is required to obtain free chlorine residual for better disinfection. So the chlorine dose has been fixed in such a way that after completion of "breakpoint" chlorination, at least 0.5 mg/L chlorine remains in water. A graphical presentation of Ammonia concentration and Optimized chlorine dose vs. Time has been shown in Fig. 10.

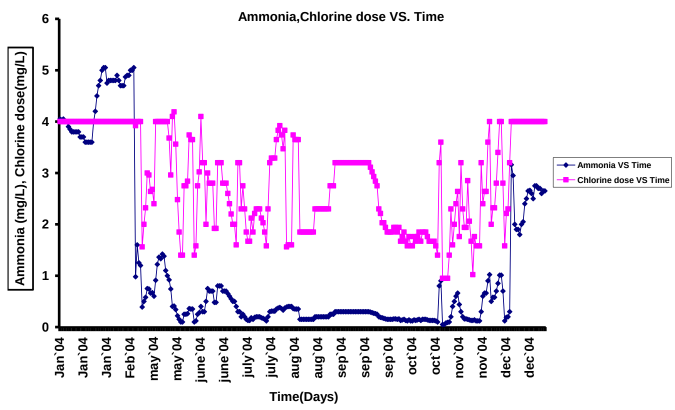

Fig. 10. Ammonia concentration and optimized chlorine dose vs. time (Days) for wet season

C) Savings from Chlorine Dose Optimization

During dry season 2004, the estimated amount of chlorine used for chlorination at SWTP was 111.15 ton. If the chlorine dose is optimized this amount can be reduced to 95.7 ton. In other words, about 14% chlorine usage can be saved.

At present the cost of chlorine per ton is Tk. 7000/=; whereas it was Tk. 37,000/= in the near past. So considering cost of chlorine, total amount of Tk. 1,08,171/= could be saved by optimizing chlorine dose at SWTP. At the rate of Tk. 37,000/= per ton, the savings would be Tk. 5, 71,761/=.

During wet season 2004 the estimated amount of chlorine used was 260.55 ton; but the optimized amount of chlorine would be 187.65 ton. Thus, about 28% chlorine usage could be reduced. Similarly considering cost of chlorine, total amount of Tk. 5,10,300/= could be saved at SWTP. At the rate of Tk. 37,000/= per ton, the savings would be Tk. 26,97,300/=.

However, cost reduction is not the only benefit from optimization of chlorine dose. Certain chlorine species, such as dichloramine could give rise to odor and taste problems. Optimization of chlorine dose could eliminate such problems.

CONCLUSION

The major findings of this report are as follows

- Raw water at SWTP has a clear seasonal variation. During wet season the concentration of a number of water quality constituents, including ammonia, get reduced significantly due to dilution by rain water / upstream fresh water. High ammonia and algae (data not reported in this study) appears to be the major water quality problem of raw water at the SWTP.
- Removal of ammonia or conversion of ammonia to nitrate is insignificant within the treatment plant.
- Higher chlorine doses (6.5 mg/l) are applied during the dry season (July to November) to take care of high ammonia concentration), while lower doses (4 mg/l) are applied during the wet season (December to June). Because of the presence of ammonia, the applied chlorine exists in treated water mostly as chloramines, with very little free chlorine.
- In this study chlorine optimum chlorine dose has been estimated based on Cl_2 to Ammonia concentration ratio, so that only monochloramine (which is an effective disinfectant) is formed during the dry season, and free chlorine (about 0.5 mg/l) is available during wet season. This will not only improve effectiveness of chlorination, but will also reduce treatment cost.
- The current practice of chlorination is likely to produce undesirable chloramines (e.g., dichloramine and nitrogen trichloride) in treated water an may cause taste and odor problems, while at the same time increase treatment cost.

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