Journal of Civil Engineering (IEB), 44 (1) (2016) 21-28

Journal of Civil Engineering IEB

Biological pretreatment of the Shitalakshya River water at Dhaka: A pilot study for ammonia removal

Md. Serajuddin[1] and Md. Mujibur Rahman[2]

[1]Life Fellow, Institution of Engineers, Bangladesh
[2]Department of Civil Engineering
Bangladesh University of Engineering & Technology, Dhaka 1000, Bangladesh

Received 20 August 2015

Abstract

The water quality of the Shitalakshya River, the raw water source of Saidabad Surface Water Treatment Plant at Dhaka, the largest treatment plant of Bangladesh, is deteriorated so much that its treatment by conventional water treatment plant has become impossible. In the dry season there are complaints of water with bad smell and aesthetic problem. There is an underlying assumption that the problems observed during dry season are linked to problems of removing algae. This problem is again assumed to be caused by increased concentrations of ammonia interfering with the intended removal of algae. In order to improve water quality of the said source before entering into main treatment chain, a pilot study was conducted to pre-treat the raw water. The objective of the present pilot study is to investigate the reduction of ammonia using the meteor pilot, a biological pretreatment system, which is a laboratory scale moving bed bioreactor (MBBR) with a nominal volume of hundred liters, filled with 50 liters of meteor 660 media. Reduction of ammonia & COD and raw water oxygen demands were evaluated in detail. The reduction of ammonia was quit significant on average 73%, while the reduction of COD was in a range from 20 to 60% and the oxygen demands was highest 99 mg/l. The meteor pilot was effectively able to treat and nitrify the Shitalakshya raw water during the dry season and produce an effluent that respect the guarantee of ammonia <4.0 mgNH_3-N/l, when the raw water ammonia concentration was <15 mg NH_3-N/l.

Keywords: Moving Bed Bioreactor (MBBR), Shitalakshya river raw water, ammonia removal, drinking water treatment, biological nitrification.

1. Introduction

Dhaka, the capital of Bangladesh and a premature megacity of today, with a population of 15 million, is almost 87% dependent on ground water for its potable water. Once, presumably cheap and abundant, ground water source inside Dhaka has gradually been depleted so much that no further over extraction is possible. There is no other way but switch over to surface water. In this context, Saidabad Water Treatment Plant (SWTP) was constructed with a capacity of 225 mld and put into operation on July 27, 2002. The Shitalakshya River at the eastern periphery of Dhaka city is the source of raw water for the SWTP (Figure 1).

Sitalakya River is one of the largest drinking water sources in Dhaka, Bangladesh feeding SWTP which is now faced with serious problems caused by pollution. The tap water quality of the water supply system, which abstract water from Sitalakya River, cannot meet increasingly stringer drinking water quality criteria due to limitation of conventional drinking water treatment. In the treatment chain different treatment processes namely pre-chlorination, coagulation, filtration, disinfection, pH correction are used at SWTP to make the water potable as well as wholesome to the consumers.

In the dry season there are complains of water with bad smell and aesthetic problem. There is an underlying assumption that the problems observed during the dry season are linked to problems of removing algae. This problem is again assumed to be caused by increased concentrations of ammonia interfering with the intended removal of algae.

Fig. 1. Raw water source and its transmission network from Lakhya River through DND canal to SWTP.

Looking at the available data and the rather complex situation of water quality it may be said that the observed problem of taste, smell and color of the treated water during the dry seasons, is due to a combination of many cause effect relations. One of which is:

– High ammonia concentration → difficult to disinfect → not possible to control algae fully nor to ensure hygienic quality of water.

During formulation of the project of Saidabad Water Treatment Plant Phase-II a specific feasibility study was conducted for the probable options for pretreatment of the raw water of Saidabad Water Treatment Plant Phase-II. The TOR for the feasibility study includes three main options for pretreatment to be investigated:

– Nitrification and de-nitrification-if needed
– Stripping of ammonia
– Break point chlorination

All of the above options were selected from the hypothesis that the problems are related mainly to the existence of high ammonia concentrations during the dry season and that a removal of the ammonia will make it possible to operate a normal treatment system to a satisfactory result. In the feasibility study it was concluded that,

– Nitrifications likely to solve the ammonia problem and partly the sulphides and organic carbon problems but will within near future add a problem of not being able to comply with the Bangladesh Standard for nitrate.

The water which is presently flowing into the Water Treatment Plant during the dry season contains high concentrations of ammonia, TOC and some sulphide, all representing a high oxygen demand. Roughly the oxygen demand can be estimated as follows:

- 10 mg ammonia require around 40 mg oxygen
- 50 mg TOC require around 50 mg oxygen
- 1-20 mg sulphide require around 2-40 mg oxygen

This will during the worst months give a total oxygen demand of around 130 mg O_2/1. Biological pretreatment process (prior to conventional treatment chain) is considered as an economic and effective treatment process to remove pollutants from raw water.

MBBR is an innovative fixed biofilm reactor, which has gained increasing attention from wastewater treatment industry. It has been successfully applied for full-scale treatment of municipal and industrial wastewaters. MBBR is a continuously operating non-cloggable biofilm reactor with no need for backwashing low head-loss and high specific biofilm grow on small carrier elements that move along with the water in the reactor. The movement is normally caused by aeration in the aerobic version of the reactor. (Pastorelli 1997; Rusten 1996; Aspegren 1998).

In order to improve water quality of the source of drinking water and mitigate load of drinking water of the Saidabad Surface Water Treatment Plant at Dhaka, a pilot study was conducted with a laboratory scale moving bed bioreactor (MBBR) to pre-treat the raw water of the Sitalakya River, the source of raw water of the treatment plant.

The objective of the present pilot study is to investigate the reduction of ammonia using the Meteor pilot, as it is named, a biological pretreatment system, which is a laboratory scale moving bed bioreactor (MBBR). Reduction of ammonia & COD and raw water oxygen demands were evaluated in detail, which could be very useful and fundamental data for the design of future water supply project taking Shitalakshya River water as raw water source.

2. Material and methods

2.1 Experimental setup (meteor pilot unit)

A MBBR bioreactor (Figure 2) known as Meteor was used to investigate the feasibility of biological pretreatment of Shitalakshya River water.

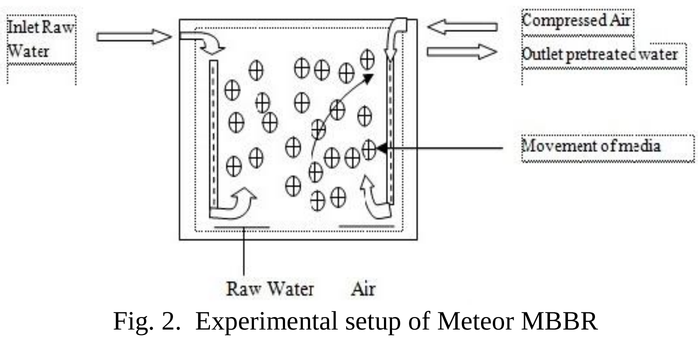

Fig. 2. Experimental setup of Meteor MBBR

The Meteor pilot is a laboratory scale moving bed bioreactor (MBBR) with a nominal volume of 100 liters, filled with 50 liters of the Meteor 660 media. The reactor is equipped with one Flexazur fine bubble aeration tube (length: 35 cm), a raw water inlet pipe and a treated water effluent pipe fitted with a media retention screen. The aeration is located against one side at the bottom of the reactor to create a spiral flow and thus provide good mixing of the media.

The raw water coming from the inlet of the water treatment plant is pumped at a controlled rate into the bottom of the reactor, and the effluent leaves the reactor through the media retaining screen and flows by gravity to a drain in the laboratory. The range of flow rate was controlled from 0.5 to 2.0 L/min, with a few excursions to slightly higher flows (3.0 L/min). A flow rate of 2.0 L/min corresponds to the full-scale Meteor design hydraulic retention time of 50 minutes. Compressed air is fed to the diffuser at rates from 6 to 40 L/min, depending on the loading rates and dissolved oxygen measurements.

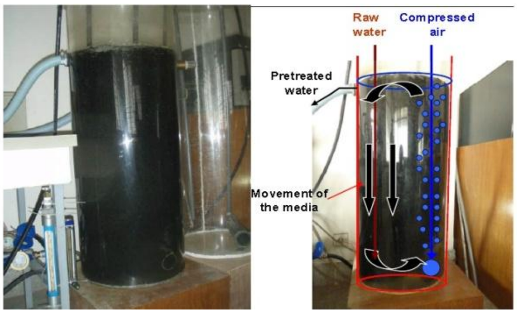

Fig. 3. Meteor Pilot Unit & Flow Diagram.

Figure 9: Meteor Pilot Effluent Pipe with Media Retaining Screen.

Fig. 4. Meteor Pilot Effluent pipe with Media Retaining Screen Unit & Flow Diagram.

Fig. 5. Meteor 360 media.

3. Results and discussions

3.1 Start-up period

The pilot unit operation started on February 9, 2011, at a feed flow rate of 0.5 L/min (HRT = 3.3 hours), with a process air flow rate of 6 L/min, which was sufficient to provide good mixing. Progressively the nitrification process began and the effluent ammonia concentration decreased to below 2.0 mg NH_3-N/L within 12 days. Thus the nitrification biofilm was developed on the media and the process established within a period of two weeks. By March 6th the pilot was operating consistently at the design flow of 2.0 L/min.

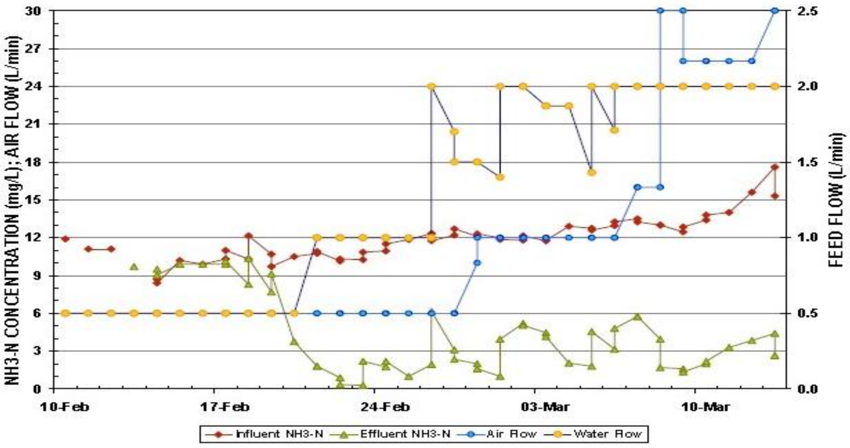

Fig. 6. Ammonia concentrations during start-up

The process air was also increased progressively from 6 to 12 and eventually up to 30 L/min. The immediate response to the increased air on March 8th, decrease in the effluent NH_3-N to < 4.0 mg/L, demonstrates that the oxygen was a limiting factor for the prior days when running at the design water flow rate of 2.0 L/min. The design removal of 11 mg NH_3-N/L was achieved within 27 days of operation, once there was sufficient oxygen for the process.

Overall, the required time to achieve the maximum design ammonia removal rates is less than four weeks, and if sufficient air would have been provided sooner the required time would have been less, potentially on the order of three weeks. Typically the start-up of the Meteor process will coincide with the beginning of the dry-season, which will occur at the beginning of December, and the raw water ammonia concentrations will be in the range of 2 to 4 mg/L and progressively increase to 6 to 8 mg/L during a period of eight weeks. The results from the pilot study show that when starting with virgin media the process will be able to follow this increase in ammonia loading. For a situation where the process needs to start in the middle of the dry-season (high ammonia concentrations > 10 mg/L), the process can be expected to reach design removal rates after a period of approximately three weeks.

3.2 NH_3-N removal

During the first period, after the start-up was achieved, the Meteor was able to remove 11 mg/L at the design flow (Figure 6).

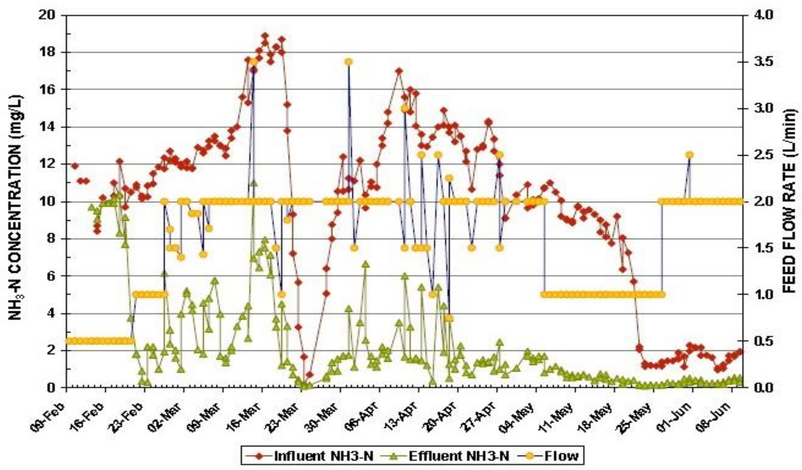

Fig. 7. Influent and effluent NH_3-N concentration water flow during study.

During period three, from March 29 through May 5 the pilot was run at 2.0 L/min (except for days when there were issues with the feed flow control) and the raw water ammonia concentrations are in the upper range: 10 to 17 mg/L. This period demonstrates well the full capacity of the process, with average removed ammonia of 11 mg/L, and a maximum removed ammonia of 13.5 mg/L. During this period the effluent NH_3-N is maintained below 4.0 mg/L (excluding the days when feed flow rate is > 2.0 L/min), with an average effluent NH_3-N of 1.7 mg/L (excluding days when feed flow rate is not 2.0 L/min).

3.3 Cod removal and raw water oxygen demand

The raw water total COD varied significantly during the study, from 10 mg/L to 84 mg/L, with similar general trends in variation of concentration as the ammonia. The average ratio of soluble/total COD in the raw water is 79%, which is higher than typical for municipal wastewaters.

The COD removal based on the influent total COD minus the effluent soluble COD provides a calculation of the maximum amount of carbonaceous pollution removed in the Meteor pilot unit. It also represents the maximum overall oxygen consumed for the oxidation of pollutants in the raw water other than ammonia. Figure 7 shows the total raw water COD, effluent soluble COD and a calculated COD removal (the difference between these two values) during the period when these analyses were made. During period 3, from 12/4/11 through 21/5, the COD removal was in a range from 13 to 52 mg/L, with 4 days having COD removal in the range from 30 to 50 mg/L. Thus the biological process was able to remove more carbonaceous pollution than the design values and at the same time remove the required ammonia load. Noted that there still remains 10 to 40 mg/L of soluble COD that is not removed by the biological treatment because this fraction of the COD is non-biodegradable. The very high ratio of COD/BOD in the raw water (5 on average) also attests to the fact that the water is not very biodegradable. Therefore, the results demonstrate that there are forms of dissolved pollution present in the raw water that are not removed by biological treatment.

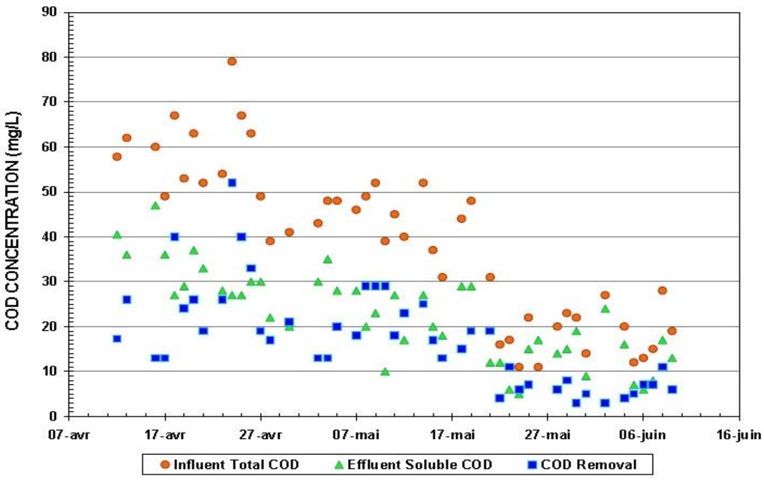

Fig. 8. COD removal

These results show that the oxygen demand of the raw water (not including the ammonia oxygen demand) exceeds the limit of 30 mg/L defined in the feasibility study. Since the measured levels of sulfide in the raw water were insignificant, this means that the level of carbonaceous pollutants is higher than expected. The results show that oxygen demands higher than 30 mg/L will occur during periods of peak pollution coinciding with the peak ammonia concentrations.

A comparison of the actual oxygen consumed in the pilot study (due to both COD and ammonia removal) and the design oxygen demand value for the Meteor process demonstrate that during the peak pollution period in April 2011 the raw water exerted a higher oxygen demand than the full-scale design. Noted that the full-scale design oxygen demand, based on the feasibility study, is 75 mg/L (30 mg/L for carbonaceous pollutants and sulfides + 45 mg/L for ammonia removal). Figure 8 plots both the COD and ammonia removed during the period of April 11th through the end of the study, including the total oxygen consumed values based on: mg/L COD removed + 4.57 x mg NH_3-N/L.

Seven days surpass the maximum design of 75 mg/L, and reach a maximum value of 99 mg/L. No similar COD data is available for the largest pollution peak in March, however clearly during the periods of raw water ammonia concentrations above 15 mg/L, the oxygen demand (to remove the COD and the ammonia down to 4.0 mg/L) will be above the design 75 mg/L. During these periods, the aeration will be a limiting factor and may not allow the removal of more than the design ammonia load.

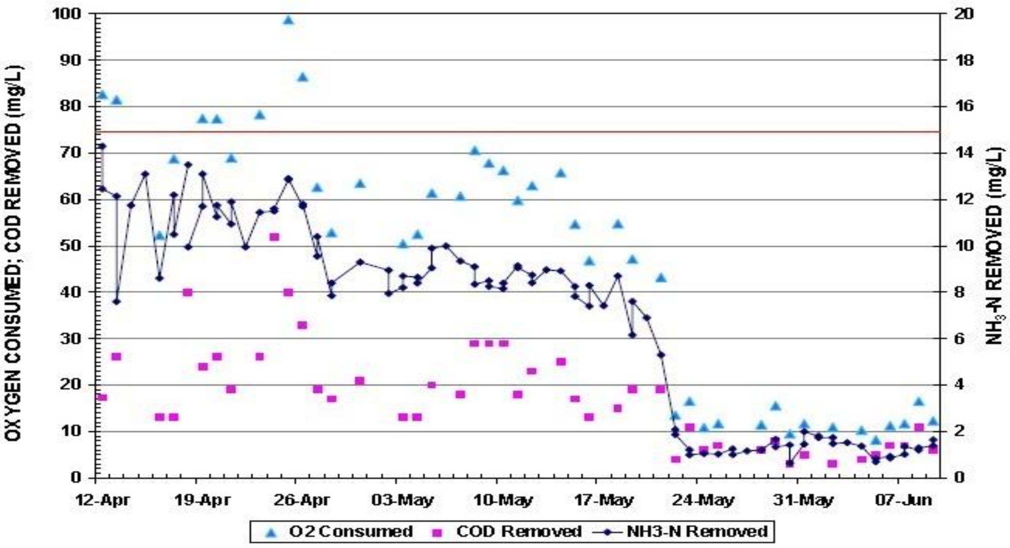

Fig. 9. Oxygen Consumption

4. Conclusion

The Meteor pilot was effectively able to treat and nitrify the Saidabad raw water during the dry-season and produce an effluent that respects the guarantees for ammonia < 4.0 mg NH_3-N/L, when the raw water ammonia concentration was < 15 mg NH_3-N/L. No significant level of sulfides were measured in the raw water or treated water, therefore the guarantee of < 0.1 mg/L S^{2-}/L in the effluent was easily achieved.

The acclimation time required to establish the nitrification process was 2 weeks, and the total time required to achieve the maximum design removal of ammonia (removed SLR of 0.99 g NH_3-N/m2/d, including assimilation) was 27 days. Thus the scheduled time of 3 weeks required for full-scale start-up, at the beginning of the dry season with low ammonia concentrations (thus low loads to remove) remains valid. For the case of full-scale start-up in the middle of the dry-season (high ammonia concentrations > 10 mg/L), the process can be expected to reach design removal rates within a period of 3 to 4 weeks.

The amount of COD removed in the pilot demonstrates an oxygen demand surpassing the design value of 30 mg/L (for carbonaceous and pollution other than ammonia). The periods of high COD removal coincide with periods of high ammonia concentrations and therefore the overall oxygen demand of the raw water during the peak periods surpassed the design total oxygen demand of 75 mg/L. During the periods when the oxygen supply is a limiting factor, due to excessive pollution in the raw water, the following negative impacts on the biological process performance and WTP are likely to occur:

- The ammonia in the pretreatment effluent will be > 4.0 mg/L, thus overloading the chlorination capacity of the WTP.
- An unstable nitrification process due to ammonia overloading, and lack of oxygen, will produce nitrite NO2-N, which will exert a chlorine demand and overload the chlorination capacity of the WTP.
- Excessive residual soluble COD pollution will not be removed in the WTP and can interfere with the operation and performance of the WTP.
- As expected, during the periods of peak ammonia concentration in the raw water, the amount of ammonia nitrified and thus nitrate produced was > 10 mg NO3-N/L, exceeding the nitrate standard for drinking water During the pilot study the influent NH_3-N > 15 mg/L for 20 days, and the amount of NH_3-N removed was > 11 mg/L for 42 days.

Acknowledgements

A number of advisers and technical helpers were involved in the development & implementation of the biological nitrification pilot plant from M/s Degremont, the constructor of Saidabad Water Treatment plant project and this co-operation is greatly appreciated.

References

Aspegren H, Nyberg U Andersson B et at., 1998. Post denitrification in a moving bed biofilm reactor process.Wat. Sci. Tech, 38(1):31-38.

DWASA,2006, Feasibility Study on Alternative intake for Saidabad Water Treatment Plant, Dhaka, Final Report. Conducted by DMP,AQUA,IWM.

DWASA,2007, Joint Feasibility Study of Pre-treatment for water supply for the Saidabad Water Treatment Plant, Dhaka, Bangladesh, Conducted by Grontmij │Carl Bro Final report.

IWM, 2004, Study to Investigate Alternate Location of the Intake of the Saidabad Water Treatment Plant, Final Report, DWASA. Institute of Water modeling and BUET Dhaka, Bangladesh.

Pastorelli G, Andreottola G, et al., 1997. Pilot-plant experiments with moving-bed biofilm reactors.Wat. Sci. Tech, 36(1):43-50.

Rusten B, Siljudlen JG, and Strand H, 1996. Upgrading of a biological-chemical treatment plant for cheese factory waste water. Wat.Sci Tech, 34(11):41-49.

Serajuddin and Mujibur Rahman, 2011, "Issue of Raw Water Quality in the Treatment of Drinking Water at Dhaka" proceedings of the ICETCESD 2011, SUST, Bangladesh.

XIE Shee-guang; TANG Xiro-Yan, et al., 2005. Biological pretreatment of Yellow river water. Journal of Environmental science vol 17, no.4, pp-557-561.