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# Performance of a Biological Pre-Treatment Unit in a Municipal Water Treatment Plant

**Md. Serajuddin[1*], Md. Aktarul Islam Chowdhury[1], Tahmina Ferdous[2]**
[1]Department of Civil & Environmental Engg (CEE), Shahjalal University of Science & Technology (SUST), Sylhet 3114, Bangladesh
[2]SUEZ International (Bangladesh Branch), Dhaka 1000, Bangladesh

**Original Research Article**

***Corresponding author**
*Md. Serajuddin*

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**Abstract:** Excessive ammonia pollution in the source river water of the largest municipal water treatment plant in Bangladesh is beyond the capacity of removal by a conventional treatment process. In order to reduce, primarily, the ammonia from the raw water before it enters into the main treatment chain a full-scale biological pre-treatment unit 'Meteor'- a ' Moving Bed Biofilm Reactor' was installed & put at the beginning of the conventional treatment chain. The reduction of ammonia was quite significant, on average 93% of the design value, while the reduction of COD was in a range from 46 to 76%. The Meteor was able to treat and nitrify the raw water and produce an effluent that respects the guarantee of ammonia < 4.0 mg $NH_3$-N/L when the raw water ammonia concentration was < 15 mg $NH_3$-N/L. The operating parameters necessary to achieve the desired goal was also noted. The study results would provide guidance on the probable use of a biological pre-treatment system for ammonia removal elsewhere.
**Keywords:** Biological nitrification, drinking water treatment, moving bed bio film reactor (MBBR), Sitalakhya river raw water.

## INTRODUCTION

Dhaka, once a tiny district town in the forties has grown as one of the most populous cities in the region since its inception as the capital of Bangladesh in 1971. Water Supply problem, likes many of Dhaka's problems stem from the speed with which the city has grown in an unplanned manner to its present size and its likely rapid growth in future. With the increase of population potable water demand inside Dhaka is ever increasing and the challenge of potable water supply for the teeming millions of this pre-matured megacity is intensifying with the passage of every single day [1].

With a population of 15 million, Dhaka is almost 87% dependent on groundwater for its potable water. Once, presumably cheap and abundant, groundwater source inside Dhaka has gradually been depleted so much that no further sustainable extraction is possible technically and economically [2.3]. There is no other way but switch over to surface water. The city water Authority could supply around 1950 MLD of water in 2004, out of which 87% was coming from underground. As an inevitable corollary, the agency responsible for water supply has planned to shift at least 50% of extraction of total supply to surface water sources and accordingly has been processing for surface water treatment plants [4].

In this context, Dhaka Water Treatment Plant I (WTP I) was constructed with a capacity of 225 MLD, the largest water treatment plant in the country and put into operation on July 27, 2002. The Sitalakhya river at the eastern periphery of Dhaka city is the source of raw water for the WTP I (Figure.1). A replication of a similar plant with the same size and almost similar design has been done as the second phase & put into operation in December 2012, where the third phase of 450 MLD capacities is postulated in near future [4].

Sitalakhya River for some years has been facing serious pollution problems due to man-made pollution. In the dry season, there were complaints of bad smell and colour in the supplied treated water extracted from the Sitalakhya. Overviewing at the available data and the complex water quality situation it had been said by the experts that the observed problem of taste, smell, and colour of the treated water during the dry seasons, was due to a combination of many cause-effect relations, like high ammonia concentration → difficult to disinfect→ not possible to control algae fully nor to ensure the hygienic quality of water → limitations of conventional treatment process [4].

During formulation of the project of Dhaka Phase-II idea for a pre-treatment unit came across the discussion among the policymakers. Initially, three probable options for pre-treatment were postulated, namely:

- Nitrification and de-nitrification-if needed
- Stripping of ammonia
- Breakpoint chlorination

The WTP I operational data showed a clearly increasing trend of the average monthly values and max values of ammonia, both increasing around three mg $NH_4$-N/L over the four year period from 2002 to 2006 [6].

Compared with the initial design criteria for WTP I of max 4 mg $NH_4$-N /L and with the Bangladesh Standard for Nitrate of 10 mg $NO_3$-N the increases are substantial in such a short period and the trend must be taken into consideration. In the internal discussion of the service provider, it was concluded that,

- Nitrifications might solve the ammonia problem and partly the sulfides and organic carbon problems and a biological pre-treatment process (prior to conventional treatment chain) was considered as an option which might be an economic and effective treatment process to remove said pollutants from the raw water [7]. This idea was a bit revolutionary in the context that almost no large drinking water treatment plant in the world like the Dhaka WTP ever used biological nitrification as a treatment option though it is popularly used in wastewater treatment plants. The experts proposed MBBR prior to conventional treatment chain, as an option of pre-treatment which might be an economic and effective treatment process to remove pollutants from raw water [5].

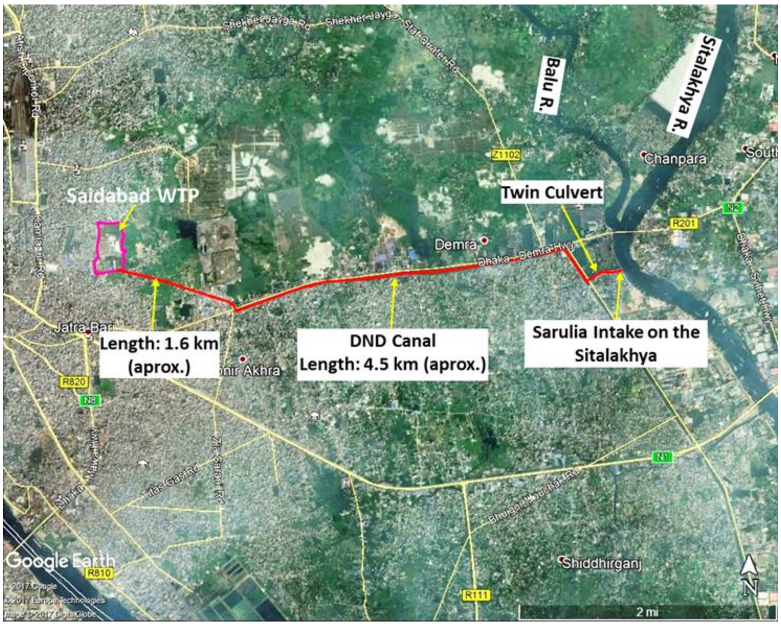


**Fig-1: Raw water source and its transmission network from Sitalakhya river through DND canal to plant**

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. It is a continuously operating non-cloggable biofilm reactor with no need for backwashing, low head-loss and high specific biofilm growth 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 [8-10]. The MBBR, first invented by Prof. Hallvard Ødegaard at Norwegian University of Science and Technology was developed in the late 1980s, in Norway on the basis of conventional activated sludge and bio-filter process [11].

Quite large numbers of literature are available on the use of biofilm reactor for the treatment of wastewater [12-19]. There are presently more than 400 large-scale wastewater treatment plants based on this process in operation in 22 different countries all over the world [15]. However, this innovative biofilm reactor has not been introduced for the pre-treatment of drinking water [20]. There is very little information in the literature on the use of biological drinking water treatment particularly on the use of MBBR [21-25]. It has been said that “Biological filtration has not been historically accepted, at least not in North America” [22]. With such backdrops, before taking the crucial and revolutionary decision of a full-scale biological pre-treatment unit for a drinking water plant in Dhaka to mitigate pollution load of drinking water, a pilot study was also conducted as feasibility with a laboratory scale MBBR [5]. The result was convincing. Finally, a full-scale MBBR pre-treatment unit was installed for the largest drinking water treatment plant in Dhaka in 2012.

The objective of the present study is to investigate primarily the rate of reduction of raw water ammonia using MBBR biological full-scale pre-treatment plant, the Meteor, as it is named, a biological pre-treatment system at Dhaka. It was intended to get the results of its performance throughout a dry season and to get some clear idea regarding its potential, as to be demonstrated in the actual operating condition, in providing a tangible & sustainable solution to those difficult challenges encountered in Dhaka water. Reduction of COD was also evaluated in detail. The outcome of this study would be very useful and reference data for the design of future water supply project in Dhaka taking the Sitalakhya river water as the raw water source & also elsewhere given that this biological process appears to be potential at those locations. The other factors those affect the efficacy of a biological treatment like time since start-up, temperature, pollution loading rate, oxygen level required, resulting oxygen in the pre-treated water, pH, sudden shock of pollution loading were also noted.

## MATERIALS & METHODS

### Meteor Reactors Operation

The six Meteor reactors (also referred to as cells, units or tanks) used for this first year of operation after it was built are named: A, B, C, F, G and H (Figure.2). This was the first full mode operation of a 225 MLD pretreatment unit utilized with urgency in 2012 for WTP I before completion of construction of a total 450 MLD pretreatment unit.

During the dry season of 2012, temporary walls were installed within the inlet and outlet channels in order to isolate the 6 cells in operation from the 4 remaining cells (D, E, I, J) which would be operated during the next dry season after phase II plant is completed.

The pretreatment unit & the water testing facility in the Dhaka plant laboratory were utilized for the study from February 6 to May 1 in 2012.

The Meteor uses the ‘Meteor 660 media’ as it is called. The description of prime characteristic features of media are as follows: the shape is corrugated cylindrical with colour black, the surface area of the media is 650 $m^2/m^3$, nominal diameter and length is 12 mm, bulk density 146 $kg/m^3$, filling rate 50%, material is a high-density polyethylene, the specific gravity is 0.95. The aeration units are located on one side at the bottom of the reactor to create a spiral flow and thus provide primary function of oxygen transfer and mixing to ensure a full utilization of the reactor volume by making each small element in the media following the circulation of the water and a uniform dispersion of dissolved oxygen throughout the mixed liquor of the reactor.

The raw water coming from the intake of the water treatment plant is pumped into the bottom of the reactor. Compressed air is fed to the meteor from the air blower installed in the plant. No external organic source other than the feed water was added to the plant from outside.

The expected & actual average and maximum concentration of different parameters are shown in Table. 1 and the targeted pre-treated raw water ammonia concentration is < 4 mg/L.

### Process air

The process aeration capacity of the pretreatment plant is 67,700 $Nm^3/h$ for 10 reactors; the nominally dedicated aeration for the phase-1 operation (using 6 reactors) is obtained by running 6 blowers (nominal flow 6,770 $Nm^3/h$ each) producing theoretically 40,620 $Nm^3/h$ at nominal speed - and in practice slightly more. The Meteor pretreatment phase-1 was accordingly operated using generally 6 blowers, or less. However, it was possible during phase-1 operation to operate the reactors with extra process air by connecting additionally available blowers to the aeration network. As the WTP-1 water production quality & quantity were critical for Dhaka city in that first year up to 8 blowers were used when critical excessive pollution was faced, raising the process aeration flow up to 8,800Nm3/h per reactor in extreme cases.

### Hydraulics

The water flow to the pretreatment phase-1 was governed by the WTP-1 demand, and ranged generally between 220,000$m^3$/d and 240,000$m^3$/d, as expected. The water level in reactors was operated at approximately 40cm below nominal level of 5.0 m. The retention time in the 6 process tanks was slightly higher (+10%) than it would be for full-scale operation of two phases of WTP, however, in the considered ranges it is known not to be a factor influencing the process. On the other hand, operating at reduced water level slightly lowered the theoretical aeration transfer efficiency. Altogether, the hydraulic conditions during the tests were similar to the full-scale pre-treatment.

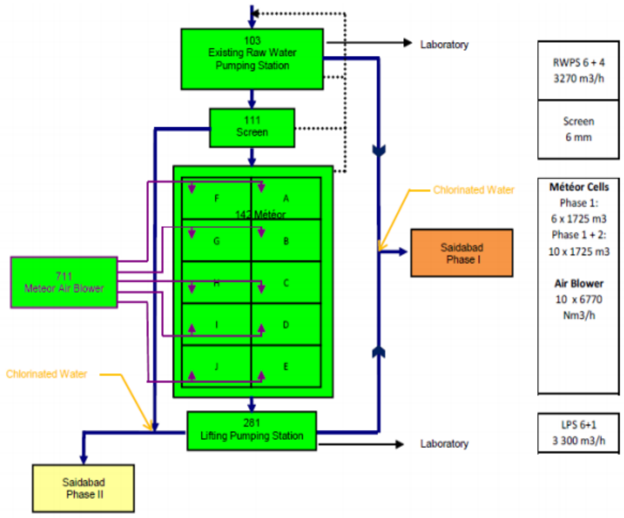


**Fig- 2: Meteor Reactors**

**Table - 1: Expected and Actual Raw water quality**

| Raw Water Quality | | | | |
|---|---|---|---|---|
| | Expected | | Actual | |
| Parameters | Average | Maximum | Average | Maximum |
| NH3-N | 4 | 15 | 14.8 | 20.3 |
| COD | 20 | 60 | 51 | 76 |
| Turbidity | 15 | 100 | 54 | 128 |
| pH | 6.5 | 8.5 | 7.4 | 7.9 |
| DO | 1 | 3 | 0.05 | 0.78 |
| Temperature | 20 | 30 | 28.35 | 31 |
| NO3 | 0.02 | 4.2 | 2.55 | 13.8 |
| PO4 | 0.3 | 4.9 | 0.53 | - |
| Sulphide | 6 | 25 | 0.04 | 0.07 |

## Water Testing and Laboratory Analysis

The water quality investigation was performed in the water testing laboratory of WTP. Some supplementary analysis was done in the laboratory of Civil Engineering Laboratory of Bangladesh University of Engineering and Technology. The internationally accepted methods of sampling and testing like APHA were used in the investigation, for example, ammonia was tested by using HACH DR 6000 spectrophotometer (HACH LANGE, USA) & Nessler method, No. 8038; COD was tested using HACH DR 890 colorimeter (HACH LANGE, USA), HACH DRB200 COD reactor (HACH LANGE, USA) & by reactor digestion.

## RESULTS & DISCUSSIONS

The Meteor reactors were filled gradually with influent water from 6/2/12 with a water flow of 1000 $m^3/h$ from the Plant 1 inlet, and from this date until 27/2/12 the reactors were only periodically aerated and fed with influent, as it was not possible to run in full capacity for some administrative reasons. The 3 weeks time period from the 6/2/12 to 27/2/12 enabled the mixing and seeding of the bio media. The full influent flow of Phase 1 was diverted on 27/2/12 to feed the Meteor units, and 6 air blowers were placed in service.

The average raw water flows from 28/2/12 through 1/5/12 was 226,000$m^3$/d. varying from 207,500 $m^3$/d to 242,500 $m^3$/d (Figure 3). During the first ten days of operation, the flow was maintained to a lower side between 207,500 $m^3$/d and 225,000 $m^3$/d due to the very high ammonia concentrations surpassing the design & expected raw water ammonia loads of 15 mg/L. Afterward, during the periods when the raw water ammonia concentrations were <15 mg/L the inlet flow was maintained to a flow value greater than 225,000 $m^3$/d. During the 14 days, the period between 17/3/12 through 30/3/12 dual sampling was done and water quality analysis was carried out simultaneously at the plant laboratory and an outside laboratory for verification & cross-checking.

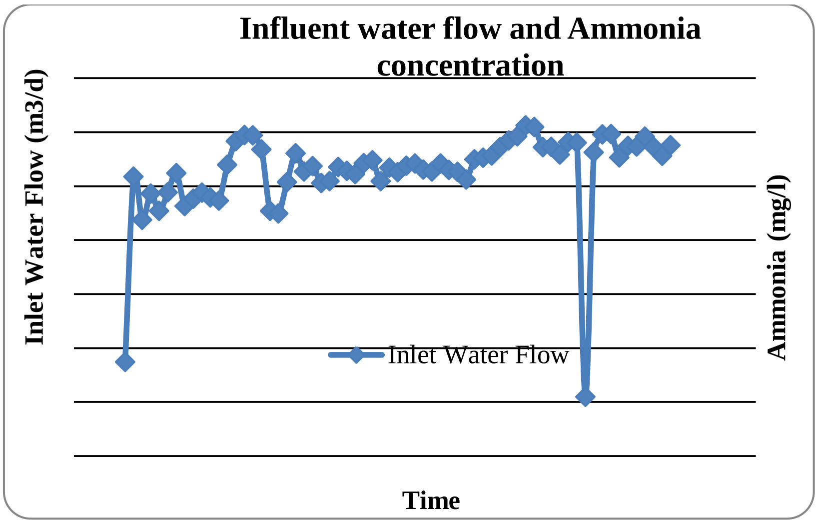


**Fig-3: Influent water flow and Ammonia concentration**

The flow was maintained between 221,131 $m^3$/d and 232,100 $m^3$/d, with an average flow for this period of 225,567 $m^3$/d. Several grid power shutdowns occurred which is visible in Figure 3 by sudden fall of water flow line. The raw water ammonia concentrations varied significantly (Figure 3), from 2.1 mg/L to 20.3 mg/L, during the 65 days period from 28/2/12 through 1/5/12. It is observed that for 48 days (74% of the time) the raw water had an ammonia concentration above the design value of 13 mg/L and 39 days (60% of the time) an ammonia concentration above the maximum value of 15 mg/L.

Figure 4 summarizes the variations in raw water and Meteor effluent temperature and pH from 28/2/12 through 1/5/12. During this period the Meteor temperature increased progressively from 25 to 31°C then starting on 6/4/12 the temperature abruptly dropped back to 25°C due to a rain event and then progressively increased again to 31°C. Overall there is no significant difference in temperature between the raw water and the Meteor effluent. The average pH of the raw water was 7.4 and that of Meteor effluent was 7.2 during this period.

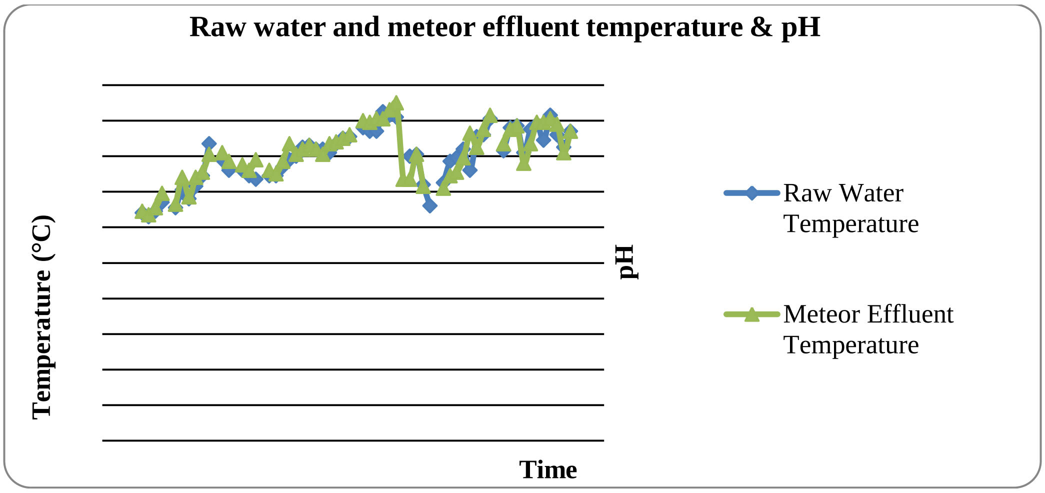


**Fig-4: Raw water and meteor effluent temperature & pH**

Figure 5 shows the dissolved oxygen (DO) in the raw water, combined Meteor & effluent. The Meteor effluent DO varied from 3 to 6.5 mg/L.

## Nitrification Performance

Figure 3 summarizes the influent & effluent ammonia concentration during the study period. Figure 6 shows the volume of air supplied to the Meteor & the quantum of ammonia removed in the Meteor. After the start-up was achieved, from 7/3/2012 through 7/4/2012 except two days the raw water has an exceptionally high level of pollution above the design concentration. Due to these high levels of pollution at least 6 process air blowers were put into operation continuously. During the two peaks pollution periods (13 days ammonia ≥ 18 mg/L) up to 8 blowers were running in order to provide sufficient oxygen for the nitrification process and verify the maximum ammonia removal rates for the 6 Meteor reactors, while feeding the WTP-1 plant with the highest possible pre-treated water quality.

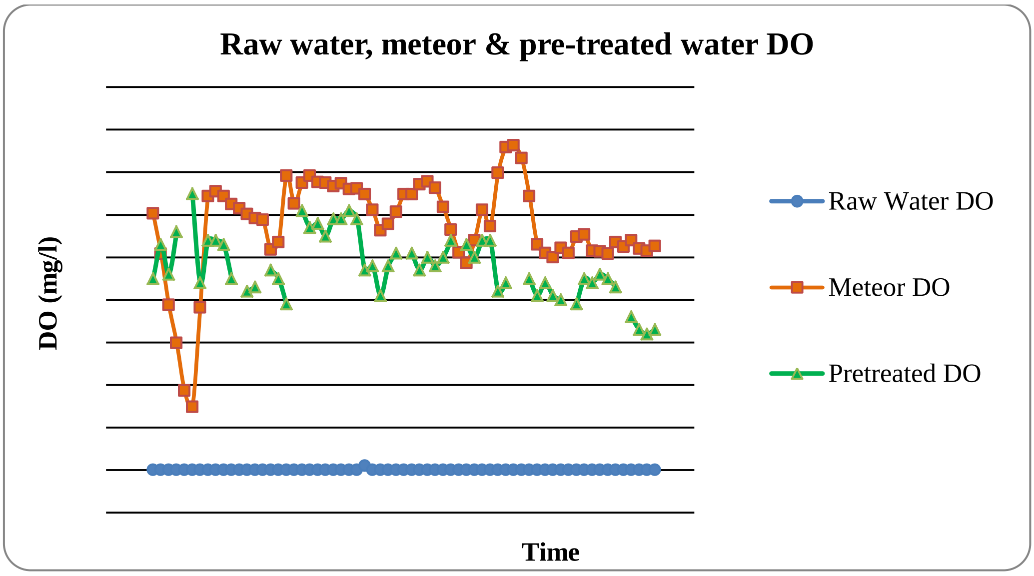


**Fig-5: Raw water, meteor & pre-treated water DO**

During the start-up period of 3 weeks, the process aeration was run close to the maximum design value of 6,770 $Nm^3/h$ for each reactor due to the high inlet loads and to ensure a quick start-up and development of the biofilm.

The six Meteor reactors were able to consistently remove ≥ 11 mg/L and the maximum con-centration of ammonia removal was 16 mg/L. The effluent ammonia concentration was al-ways < 2.0 mg/L when the raw water contained < 13 mg $NH^3$-N/L (design concentration), and < 4.0 mg/L when the raw water contained < 15 mg $NH^3$-N/L (expected maximum con-centration)but >13 mg $NH^3$-N/L.

From 8/4/12 through 15/4/12 as shown in Figure 6 the raw water ammonia decreased significantly due to a rain event and therefore the removed ammonia concentrations decreased accordingly. During this period the number of process air blowers was accordingly decreased down to three blowers corresponding to the minimum fluidization flow for 6 reactors. After the rain event, the ammonia concentration increased drastically, from <4mg/L on 13/4/12, up to >14mg/L only 4 days later. The ammonia removal followed the trend with a steady efficiency of >97% over this period; thus the reactivity of the Meteor process to sudden loading change appeared to be positive. The subsequent period, from 17/4/12 through 26/4/12 excluding Saturday (21/4/12) on which a major power shutdown occurred, is representative of the process performance under loading conditions that corresponds the closest to the maximum design conditions: Influent ammonia concentration ranging from 13.6 to 16.5 mg/L; average = 15.1 mg/L - Water flow rate ranging from 230,500 to 239,250 $m^3/d$; average = 234,970 $m^3/d$ - Process aeration ranging from 32,500 to 42,500 $Nm^3/H$; average = 35,795 $Nm^3/H$ - Dissolved oxygen ranging from 4.0 to 6.4 mg/L; average = 5.2 mg/L.

Furthermore, by increasing the Meteor process aeration it has been demonstrated that higher ammonia loads can be removed during the periods when exceptionally high ammonia pollution is present in the raw water.

**Removal of COD**

The raw water total COD concentration varied significantly during the study period, from 21 mg/L to 76 mg/L, with similar general trends in the variation of concentration as the ammonia. Figure 7 shows the total raw water COD, effluent total, and soluble COD. The COD removal can be calculated based on the influent total COD minus the effluent total COD. This calculated "minimum" removal averaged 16 mg/L with a maximum of 35 mg/L.

On the other hand, the calculation of COD removal based on the influent total COD minus the effluent soluble COD provides the maximum amount of carbonaceous pollution removed in the Meteor process. It also represents the maximum overall oxygen consumed for the oxidation of pollutants in the raw water other than ammonia. This calculated "maximum" removal averaged 29 mg/L, with a maximum of 51 mg/L.

During the periods where the influent pollution concentration was exceptionally high correspond to the period where additional blowers were placed in operation. During these exceptional peaks of pollution, and despite the increased aeration the ammonia removal efficiency significantly decreased. For removing such loads during the pollution peaks it was necessary to maintain the process aeration at a significantly higher level than during the later period: up to +50% processes air was necessary for achieving similar process performances.

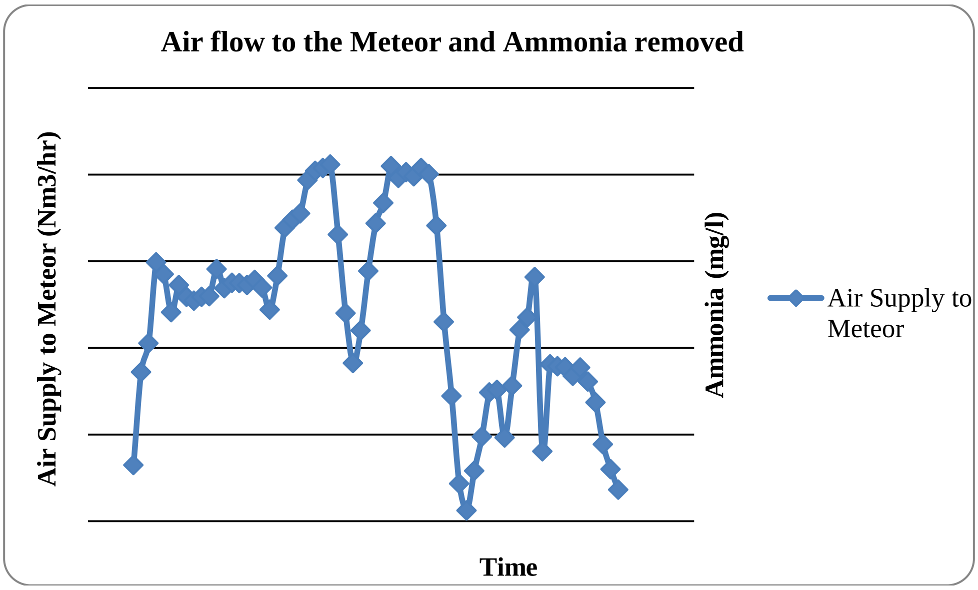


Fig-6: Air flow to the Meteor and Ammonia removed

However, when the influent concentration reached exceptionally high levels (~18mg/L), and possibly because of the presence of specific industrial pollutants, the nominal aeration capacity was not sufficient to fully address the excess of pollution and consequently, additional blowers had to be placed in operation.

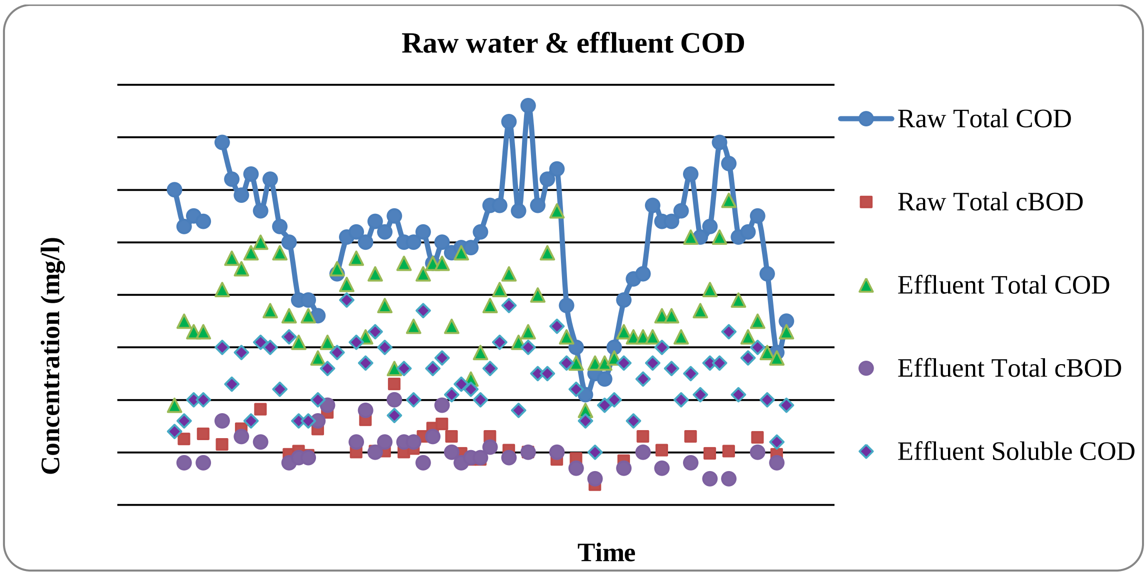


Fig-7: Raw water & effluent COD

## CONCLUSIONS

The performance of a full-scale biological pretreatment unit equipped with MBBR in a municipal water treatment plant was studied. The targeted removal of 11mg/L of ammonia was possible. It took three weeks to fully develop the system and full-scale startup since commissioning. In the beginning, the ammonia concentration was low with low removal rate. Along with ammonia, the process can remove COD also from the raw water. But COD will compete with the ammonia. There must be a provision of adequate time in the treatment plant necessary to establish the nitrification process to start up fully. It will be risky in the context of quality to start the pre-treatment in the middle of the dry season with high ammonia content in raw water.

The 56 days of performance monitoring from 7/3/2012 to 1/5/2012, fully demonstrate that the process meets all effluent guarantees and performance criteria.
Meteor effluent consistently meets the requirements:
$NH_3$-N/L < 2.0 mg/L when influent concentration < 13 mg/L
$NH_3$-N/L < 4.0 mg/L when influent concentration < 15 mg/L

As a summary of the pretreatment operation during the monitored period, the Meteor unit operated with 6 reactors, removed:

- ≥ 11 mg $NH_3$-N/L during 47 days (84% of the period),
- ≥ 13 mg $NH_3$-N/L during 31 days (55% of the period),
- Up to 16 mg NH3-N/L
- in average 99% of the influent ammonia when influent < 13 mg/L
- in average 93% of the influent ammonia when 13 < influent < 15 mg/L
- in average 84% of the influent ammonia when 15 < influent < 18 mg/L
- in average 74% of the influent ammonia when influent > 18 mg/L

During 18days (32% of the time), where the influent ammonia concentration averaged 18 mg/L and reached >20mg/L, the reactors were boosted using 7 or 8 blowers (instead of only 6 available for 6 reactors when in normal operating conditions), so as to maintain a pretreated effluent as close as possible to the WTP-1 inlet maximum criteria, despite the over-design pollutant loads.

The analytical results of the raw water during this 56 days monitoring period indicate again this year that the pollutant loads and concentrations are significantly higher, and that the dry-season lasts longer than assumed in the design. In particular, following characteristics of the influent water were observed during the period:

- ≥ 13 mg $NH_3$-N/L during 39 days (70% of the period)
- ≥ 15 mg $NH_3$-N/L during 31 days (55% of the period)
- Up to 21 mg $NH_3$-N/L

However, the pretreatment configuration used during the 2012 dry season was different from the future configuration when both WTP1 and WTP2 conventional plants will be in operation: 6 reactors were in operation this year, versus 5 for each WTP in future (i.e.: +20%) up to 8 blowers were in operation this year, versus 5 for each WTP in future (i.e.: up to +60%).

In case the raw water pollution continues to reach the exceptionally high levels observed in 2012, the situation would require certain actions to enable the existingWTP1 and future WTP2 meeting the treated effluent quality requirements during the dry season.

During the periods when the oxygen supply is a limiting factor, due to the probable 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 $NO_2$-N, which will exert a chlorine demand and overload the chlorination capacity of the water treatment plant (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 would be > 10 mg $NO_3$-N/L, exceeding the nitrate standard for drinking water.
- The raw water at Dhaka plant seems to have a fairly high alkalinity – especially during the dry season (150-250 mg/L). It is therefore unlikely that addition of chemicals becomes necessary.

Nitrification as pre-treatment would be an option, but not an ideal one, since the removal of too much ammonia would demand de-nitrification also soon in the process. The economic & financial analysis including the opportunity cost of the total system should be assessed as a part of the feasibility.

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