Restoration of Hatirjheel Lake by designing submerged aeration system and settling zone

Fabliha Anber¹, Nazeat Ameen Iqra² and A.B.M. Badruzzaman³
¹Department of Civil engineering, Bangladesh University of Engineering and Technology, BUET Central Road, Dhaka-1000, Bangladesh
²Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, BUET Central Road, Dhaka-1000, Bangladesh
³Professor of Department of Civil Engineering, Bangladesh University of Engineering and Technology, Bangladesh

Abstract. Hatirjheel Lake is known as the centre of the Dhaka city, the capital of the Bangladesh, a South Asian riverine country. But, unfortunately, soon this lake will be darken due to huge pollution. Therefore, to augment dissolve oxygen level, aeration system has been acknowledged as an effective way for the lake restoration, and an aeration zone and for further improvement settling zone have been designed. First of all, our study is assessed bifurcating the total area into two segments: aeration zone and sedimentation zone. Total oxygen requirement and other fundamental tests have been derived from sample. Later, to meet 83mg/l of oxygen demand number of diffusers of 8in diameter have been enumerated, and additionally three root lobe blowers of a centrifugal pump are selected, and desludging time interval has been computed. Conclusively, the percentage removal of particles has been substantialized through laboratory-based batch column. In our study, we have considered maximum discharge of 6 ft³/s whilst even during the rainy season more than 50% incoming water will be transferred via twin diversion sewers. Therefore, we can say our design is in the satisfactory zone.

1. Introduction
Wastewater Aeration system is the process of adding air into water body to allow aerobic bio-degradation of the pollutant components. It has been an integrated part of the most biological wastewater system especially in municipal and industrial treatment. The more effective an aeration system will be; the wastewater treatment will be more sustainable. With the increasing amount of polluted water bodies, aeration system works as simple as effective by providing oxygen to bacteria artificially to decompose welly the organic matter and also generating carbon-di-oxide and water. Most wastewater treatment plants operate their aeration zones and aerobic digesters at 1-3 mg/L dissolved oxygen (DO). The efficiency of aeration depends on the amount of surface contact between air and water, which is controlled primarily by the size of the water drop or air bubble [1]. In terms of our context we are using diffused aeration system introducing small bubbles of air into the water, and allowing wastewater to get treated. The benefits of aeration system are unprecedented: (a) volatile organic matters such as benzene (found in gasoline), or trichloroethylene, dichloroethylene, and perchloroethylene (used in dry-cleaning or industrial processes), even other metal oxides and other undesirable metals can be removed by aeration; (b) Surface waters have low carbon dioxide content, generally in the range of 0 to 2 mg/l. Water from a deep lake or a reservoir can have high carbon dioxide content. It may be 50 to 300 mg/l. But aeration can reduce the carbon dioxide content of the water to as little as 4.5 mg/l. Naturally present heterotrophic organisms use O₂ to respire the organic
carbon that is biologically available and any chemicals that spontaneously react with O₂ (e.g., sulphide) will also do so, allowing analysts to assess total BOD in wastewaters [2]; (c) The goal of most fish farmers is to maximize production and profits while holding labour and management efforts to the minimum. Aeration offers the most immediate and practical solution to water quality problem creating an acceptable environment for the fishes and other aquatic lives [3]. In addition, an example of the success of aeration system will definitely be Bahia Del Mar Lake Restoration. It is situated on the western coast of Florida, and only aeration system causes BOD from 385mg/l to 2.5 mg/l – around 99% of reduction. The lake which was hackneyed before 2012, now is the domicile of aquatic lives [4].

This study addresses two assessments. The first is to characterize the wastewater sample taken from Hatirjheel, evaluating required specifications for executing oxygen demand and eventually searching an efficient way related to transfer oxygen to the waste water. Designing aeration zone, there were various methods to use whereas we chose fine bubble diffuser rather than coarse bubble diffuser it’s because fine bubble diffusers have more oxygen transfer efficiency than coarse bubble diffusers. Coarse bubble diffusers are more economical and require less maintenance, but have lower oxygen transfer efficiency [5]. It is a matter of fact that we chose submerged aeration system not because just to purify the total lake from bottom to the top but also this bottom up aeration reduces thermal stratification. Generally for these systems the compressed air is injected at lowest point in the treatment tank below the aerators by using blowers. Then the aerators disperse the air bubbles, which are in turn distributed in the water during their rising upward to the surface. Low volatile organic compounds (VOC) are released to the atmosphere by submerged aeration [6]. This is more effective than surface aeration. Bottom aeration in tanks and ponds uses compressed air to add oxygen to water. It can also be used as a treatment processes such as coagulation and flocculation addition or filtering systems [7]. The second is to design a settling zone and assessing required specifications for sludge removal, consisting turbidity and TSS test and analysis pertaining to it. This research investigated on searching a solution for efficiently and economically rescinding organic materials by designing optimal aeration system and further treating with designing a settling zone.

2. Methodology

2.1. Studying sample area
The sample was collected from SSDS-1 point of Hatirjheel. Hatirjheel Lake is the reservoir of one third of the catchment area of the city and there is a high variation in its water level between the dry and wet seasons (from May to October), with a normal flood-level of 4.6 meters and a water level at 6 meters or more during extreme rainfall [8]. It receives enormous amount of storm run-off, domestic waste water and industrial wastewater through a number of major outlets, and in monsoon it intensifies.

2.2. Analytical Methods and Wastewater Composition
This research includes assessing total amount of oxygen required to obliterate the microorganisms, and also to design aeration system. The amount of oxygen required by micro-organisms to metabolize the organic matters in the water is known as Biochemical Oxygen Demand (BOD) [9]. It is a measure of the amount of oxidized substances in a water sample that can lower DO concentrations [10]. To determine we used following formula [10]. The general equation for the determination of a BOD₅ value is:

\[
\text{BOD}_5 \text{ (mg/L)} = \frac{(D_1 - D_2)}{P}
\]

Where,
\(D_1\) = initial DO of the sample,
\(D_2\) = final DO of the sample after 5 days, and
\(P\) = decimal volumetric fraction of sample used.

With the obtained BOD value, we designed an aeration system described below. This research also includes designing a settling zone to get the removal time of the sludge along with evaluating settling characteristics of sediments of the sample by Column Settling Analysis. The Suspended solids data
collected at various column depths for each sampling period can be directly used to obtain the 
average solid removal in the column [11]. For implementing this, we calculated Total Solid (TS), 
Total Dissolved Solid (TDS), and Total Suspended Solid (TSS) at different ports at 5hr time interval 
from column test and assessed turbidity at different ports at 30 min time interval from that test. The 
Waste water was analysed by various laboratory tests which are standardized by following methods 
and specifications. Our experimented data are also given in the last column which is shown in Table 1.

**Table 1. Water Quality Parameters.**

| Parameter                  | Method Used          | Equipment                        | MDL a | Laboratory Data |
|----------------------------|----------------------|----------------------------------|-------|-----------------|
| pH                         | SM 4500-H+ B         | WTW Glass Probes, HACH HQ10 pH Meter | <1    | 6.7             |
| Dissolved Oxygen (DO)      | SM 4500-O B & G      | WTW DO meter                      | 0.1 mg/L | 0.14        |
| Electrical Conductivity (EC)| SM 2510 B           | WTW EC Probes, HACH EC Probes    | 0.1 µS/cm | 570       |
| Ammonia-Nitrogen (NH3-N)   | SM 4500-NH3 B        | DR 4000 UV Spectrophotometer     | 0.017 mg/L | 18.25    |
| Sulphide                   | USEPA 376.2          | DR 4000 UV Spectrophotometer     | 0.002 mg/L | 0.041     |
| Turbidity                  | SM 2130B             | Turbidimeter, DR Lange Turbidimeter | 0.01 NTU | _              |
| TDS                        | SM 2540 B-D          | Oven                             | 5 mg/L | _              |
| TSS                        | SM 2540 D            | Oven                             | 5 mg/L | _              |
| Biological Oxygen Demand (BOD)| SM 5210 D      | Winkler Bottle; OxiTop Control    | 0.2 mg/L | 60        |
| Chemical Oxygen Demand (COD)| SM 5220 D          | DR 2010 UV Spectrophotometer     | 2 mg/L | 124             |

MDL = Method Detection Limit

3. Mathematical Enumeration of Designing Sustainable and Economical System

3.1. Oxygen Calculation

Lower limit 0.9 kg O2 required for per kg BOD5 removal for low SRT plants. Upper limit 1.3 kgO2 
required for per kg BOD5 removal for high SRT plants [12]. From our experiments we got, 
Oxygen required for BOD Oxidation: 60 mg/l
Oxygen required for NH3 Oxidation (nitrification): 19 mg/l
Now, a general accepted dissolve oxygen (DO) required for large population of various fishes is 4mg/l. 
even it drops less than 3 mg/l not even a hardy fish can live. So, we added additional 4 mg/l for or 
estimation [13].

Therefore, total Oxygen required: 60+19+4 = 83 mg/l. As mentioned above, 0.9~1.3 kg O2 required 
per kg BOD5 removed and discharge rate: 611.65 m3/hr. (discharge = 6ft3/s, field inspection). So, 
oxyn required,

\[
\begin{align*}
&= 1.3 \times 83 \times 611.65 \text{ kg of O}_2/\text{hr.} = 95.99 \text{ kg of O}_2/\text{hr.} \\
&= 65.99/0.21 \text{ kg of Air/.hr.} = 314.23 \text{ kg of Air/.hr.} (21% \text{ of O}_2 \text{ in Air}) [14] \\
&= 314.23/1.2 \text{ m}^3/\text{Air/ hr.} = 261.86 \text{ m}^3/\text{Air/ hr.} (\text{Unit Wt. of Air}=1.2 \text{ kg/m}^3) \\
&= 261.86/15 \text{ m}^3/\text{Air/ hr.} \\
&= 1745.733 \text{ m}^3/\text{Air/ hr.} (\text{Standard O}_2 \text{ Transfer Efficiency (SOTE}=15\%) \\
&= 1745.733/60 \text{ m}^3/\text{Air/min.} = 29.1 \text{ m}^3/\text{Air/min}
\end{align*}
\]
3.2. Volume Calculation
The total SSDS1 had been separated into six cross sections and the volume of those cross sections had been computed with the provided elevation of that area, taken by field inspection.
For designing aeration system, we selected two suitable cross section for aeration zone.
Acquired volume is, \( V = 28918.38 + 59230.501 = 88150 \ m^3 \)

3.3. Aeration Zone
Our total SSDS1 was mainly subcategorized into two parts. One was for continuing the aeration process we name it ‘aeration zone’ and similarly was for the sedimentation system whereas we call it ‘sedimentation zone’, which will be discussed later.
Now for aeration zone, assumed, Length= 20m, Width=15m, Height=6m.
So, volume of aeration tank = length*width*height
\( = 20*15*6 \)
\( = 1800 \ m^3 \)

3.4. Air Diffuser
Disc diffuser 8”, fine bubble diffuser had been selected. The minimum spacing between 8” diffusers is 0.33m (center to center) [15].

3.4.1. No of Diffusers. Effective service area = 0.5-2.5 \ m^2 \) [16].
Therefore, number of diffusers = (15*20)/1 = 300 [Let, service area 1 \ m^2 \) [16].
As, we are taking 300 number of diffusers for 1800 \ m^3 \) area so for whole volume of SSDS1
Total number of diffusers = (300*88150)/1800
\( = 14,692 \) diffusers.

3.5. Air Blower
Oxygen demand could be met using atmospheric air that is compressed by blowers and discharged via air piping and diffusers. Blowers provide a constant volume of air over a wide range of operating discharge pressures. Hence to meet 29.1 \ m^3, \) the positive displacement, centrifugal type of blower (3 root lobe blower) was selected.

3.6. Pressure calculation
Diffuser is a device where capacity and velocity all are interrelated with pressure. We took the height of 6m from field inspection and calculated pressure.
Pressure= height * density * gravity acceleration = \( 6*1000*9.81 \)
\( = 58.86 \) KPa
\( \approx 60 \) KPa

3.7. Operation specification
We selected ANLET Company for the blowers and from their catalog we chose Japan Model: BE 200H 8B for required dissolve oxygen of 29.1 \ m^3 \) of Air/min and static pressure of 60kPa.
We selected a blower having air Capacity of 29.5m³ of air /min where RPM would be 1450 per min and power would be 41.7 KW [17].

3.7.1. Detention Time. Detention time, \( T = \) Volume/Discharge = 88150/611.65=144.12 hr=6 days

3.7.2. Operating time for a pump. Time= (pressure*volume)/power
\( = (60*103) \times 88150/ (41.7*103) = 103874.97s \approx 28.8 \) hr. (For 6 days detention time).
So, \( (28.8/6) \approx 5 \) hr. operating time for a pump per day.

3.7.3. Interval period of desludging. From batch column settling test. We got, Initial TSS=4mg/l. Final TSS=64 mg/l. The estimated TSS is 60 mg/l for 5 hr. duration.
Total sludge accumulation in 88150 \ m^3 \) is \( = (60*88150/10^{-3}) \)
\[ = 5.3 \times 109 \text{ mg} \\
= 5.3 \times 103 \text{ kg} \\
= \frac{(5.3 \times 103 \times 6 \times 24)}{5} \\
= 152640 \text{ kg (for 6 days)}.
\]
Assuming density of sludge 2000 kg/m³, Volume of total sludge is (152640/2000) = 76.32 m³. Now the design area is (88150/6) = 14692 m². Therefore, weight of the sludge is (76.32 \times 100/14692) = 0.52 cm for 6 days.

Let, the diffusers are to install 1.5m above the bottom of the lake. Hence, required time for desludging is (6\times1.5/0.0052) = 1730.8 days = (1730.8/365) = 4.7 years. For safety after every 4 years later desludging is required.

3.7.4. Cost Estimation. We chose diffusers of ANLET 3 Lobes Blower and Vacuum Pump. With the given specification we calculated 14,690 diffusers. According to ANLET Company, price of one diffuser is 2300 taka or 85 USD. Thus, our total price for the diffusers will be (85 \times 14,692) = 1,248,820 USD.

3.8. Settling Zone design

For designing settling zone, we selected another two suitable cross sections and the acquired volume is, Volume = 67652+171211 = 238863 m³.

3.8.1. Detention time. \( T = \frac{\text{Volume}}{\text{Discharge}} = 238863/ (88150/6) = 16 \text{ days} \).

3.8.2. Interval period of desludging. From column settling test, we got, Initial TSS=4mg/l, Final TSS=64 mg/l. The estimated TSS is 60 mg/l for 5 hr. duration.

Total sludge accumulation in 238863 m³ is (60 \times 238863/10³)
\[ = 1.433 \times 1010 \text{ mg} \\
= 14330 \text{ kg (for 16 hr.)} \\
= (14330 \times 16 \times 24)/5 \\
= 1100544 \text{ kg (for 16 days).}
\]
Assuming density of sludge 2000 kg/m³, Volume of the total sludge would be (1100544/2000) = 550.27 m³. Now the design area is (238863/6) = 39810.5 m². Therefore, weight of sludge is (550.27 \times 100/39810.5) = 1.38 cm for 16 days.

Let, sludge will be removed after it covers 200 cm. So required desludging time is (16 \times 200/1.38)/365 = 6.35 years. For safety after every 6 years later desludging is required.

3.9. Percentage of solids removal at different depth and time. To eliminate solids percentage from the solid water, we had done this alleviation of solids in few steps. Evaluation of turbidity of the sample at seven different ports, and seven different time had been the first order pertaining to this matter. A bar chart is shown below considering the first step. Determining initial and final TSS at seven different ports and completing regression analysis of TSS vs. Turbidity at initial and final time at those ports convicting percentage removal turbidity could be used instead of TSS had been the second order. Final step was enumerating percentage removals with the following equation and getting 20% removals at 4.5 hour where Table 2 is nothing but the illustration of that step. Here, the stated equation of Percent removal is, \( X_{ij}= \text{mass fraction removed (at ith depth at jth time interval)} = (1- \frac{C_{ij}}{C_{0}}) \times 100 \). Where, \( \text{C}_{0}= \text{turbidity at ith depth and jth interval}, \text{C}_{0}= \text{initial turbidity}. \)
Figure 1. Turbidity at different ports and different time.

Table 2. Percentage removals of solid at different depth and time.

| Depth (in) | Time (hr) |
|-----------|-----------|
|           | 2         | 2.5       | 3         | 3.5        | 4.5        |
| 6.55      | 5.49      | 8.6       | 8.53      | 13.2       | 19.84      |
| 18.50     | 5.46      | 8.25      | 11.79     | 13.17      | 20.05      |
| 30.25     | 5.42      | 7.09      | 11.47     | 13.10      | 19.77      |
| 42.00     | 5.11      | 7.04      | 9.6       | 12.89      | 19.46      |
| 53.75     | 5.10      | 5.87      | 8.51      | 12.62      | 19.44      |
| 62.50     | 5.00      | 5.82      | 8.75      | 12.07      | 17.88      |
| 67.50     | 3.33      | 4.15      | 7.97      | 12.61      | 17.02      |

4. Discussions
In this paper, from 3.1 to 3.3 design of aeration tank had been completed. Here, we also computed amount of oxygen required with which we estimated type of air blower in section 3.5. Then, Section 3.6 and 3.7 indicated the operational specifications that were required for maintaining oxygen requirement cost estimation showed economic analysis of this process. As we chose 8 in fine bubble diffuser, we enumerated no of diffusers required for the specific volume of aeration tank. Later on, in section 3.8 we designed a settling zone and with batch column settling test we calculated desludging time interval and percentage of solids removal in a specific time and depth to round off this research work. And for the safety purpose this research had completed taking more than incoming water of the lake as in discharge of 6 ft³/s. Hence, it would serve as a safe, efficient and economical process for restoration of the Hatirjheel lake.

5. Conclusions and Recommendations
Based on the research, a number of conclusions can be expressed as follows. Due to discharge of 6 ft³/s, the detention time for the aeration zone and settling zone would be 6 days and 16 days respectively with pump operating 5 hour/day. After every 4 years and 6 years interval desludging need to be done for aeration zone and settling zone respectively. The total expenditure for the diffusers would be 1,248,820 USD and approximately 20% of solids can be removed from batch settling column test within 4.5 hr. According to this research and reviews from the policy of various aerator companies, some recommendations can be envisaged. They are: (1) the actual amount of water flowing in the diversion pipe during wet season must be considered due to assess the total financial analysis. (2) the cost of installation and maintenance must be determined for further analysis. Last of all water infrastructure must be properly maintained to achieve sustainability thus improve the community welfare and future generations.
References

[1] Akhlaque S Saleem S A A H, Isa M U R Rafique S K S and Nayeeem A B N 2017 International Journal of Creative Research Thoughts (IJCRT) 5(4) 869-874

[2] Dodds W K and Whiles M R 2010 Aquatic chemistry and factors controlling nutrient cycling: Redox and O2 Freshwater ecology (second edition) (Academic Press: London) pp 289-321

[3] Atia D M Fahmy F H Ahmed N M and Dorrah H T 2012 Design and Control Strategy of Diffused Air Aeration System World Acad. Sci. Eng. Technol 6(3) 666-670

[4] DeVries R 2011 Ferric Chloride in Wastewater Treatment Environ. Sci. 2 6–26

[5] Nadayil J Mohan D Dileep K Rose M and Parambi R R P 2015 International Journal of Interdisciplinary Research and Innovations 3(2) 10-15

[6] Issa H M 2013 Characterization and improvement of a surface aerator for water treatment (Doctoral dissertation, École Doctorale Mécanique, Énergétique, Génie civil et Procédés (Toulouse): 154236012)

[7] Saunders M and Visser B 2015 Bottom Aeration Protecting Our Water Resource

[8] Peeters S and Shannon K 2011 Journal of Environmental Design and Planning 7 25-46

[9] Hocking M B 2016 Handbook of chemical technology and pollution control Elsevier

[10] Delzer G C and McKenzie S W 2003 Five-day biochemical oxygen demand: US Geological Survey Techniques of Water-Resources Investigations book 9 chapter A7 section 7.0

[11] Pise C P and Halkude S A 2011 Int J Eng Sci Technol 3(4) 3177-3183

[12] Technical Bulletin 135 2005 General Oxygen Requirements for Wastewater Treatment Environmental Dynamics International USA

[13] Hazeltine B and Bull C 2003 Field guide to appropriate technology Elsevier chapter 3 p 377

[14] The Engineering ToolBox Air - Composition and Molecular Weight available from https://www.engineeringtoolbox.com/air-composition-d_212.html accessed on 30 Aug 2019

[15] Mueller J Boyle W C and Popel H J 2002 Aeration: Principles and Practice Volume 11 CRC press chapter 3 p 155

[16] Holly Technology PTFE Membrane Fine Bubble Diffuser available from http://www.hollyep.com/html/Fine%20Bubble%20Diffusers%20Aerators/939 accessed on 30 Aug 2019

[17] Anlet Co. 2011 Anlet 3 Lobes Blower and Vacuum Pump available from http://technosave.net/pdf/anletblowers.pdf accessed on 30 Aug 2019