Efficiency Evaluation of Fluidized Aerobic Bioreactor (FAB) Based Sewage Treatment Plant Near Dal Lake in Kashmir Valley, India

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ABSTRACT

Wastewater is a global concern and its treatment is becoming a rising challenge across the globe because of the impacts it inflicts on aquatic systems and human health. Sewage treatment plants (STP's) were lately established around Dal Lake in Srinagar city to protect the aquatic environs from the sewage generated within the city. In this study we tried to understand and capture the reflections regarding the efficiency of a FAB based STP installed at Hazratbal near Dal Lake. Samples were collected at Inlet, FAB I, FAB II, Claritube settler and Outlet over a period of four months so as to get a clear picture regarding the change in the characteristics of the sewage during various treatment stages. Significant reduction ($P<0.05$) was observed in parameters like nitrate ($F=3.12$; $P=0.047$), ammonia ($F=26.96$; $P=0.000$) and chemical oxygen demand (COD) ($F=22.63$; $P=0.000$). The results reveal that the main contribution to pollution of the lake from treated sewage happens to be through the addition of organic matter in the form of parameters like BOD (Biochemical oxygen demand) (45mg/l), COD (257mgO_2/l), ammonia (1.7mg/l) and nutrients like total phosphorus (1.41mg/l) which were exceeding the Indian discharge standards in the effluent. This study, therefore, tries to attract the attention of the concerned stakeholders for a relook as the purpose of establishing STP's around Dal Lake may prove counterproductive if desired efficiency levels are not met.

Keywords: *Ammonia, BOD, Claritube settler, Discharge, Outlet, Pollution, Sewage*

INTRODUCTION

Access to clean drinking water and safe sanitation are considered as the basic needs of human beings as they are essential for sustaining healthy livelihoods and maintaining their dignity (WWDR, 2019). Currently, there is a great stress on freshwater resources due to improper waste disposal practices (Abro *et al.,* 2018; Mahessar *et al.,* 2020; Renner and Opiyo, 2021; Dar *et al.,* 2021a). Several contaminants present in wastewater constitute a danger to public health and ecosystems (Ghernaout *et al.,* 2019). Consumption of large amounts of freshwater throughout the world results in generation of huge volumes of wastewater of which more than 80% is discharged without any treatment (WWAP, 2017; Colella *et al.,* 2021). As cities outgrow their sanitation systems go straight into water bodies affecting downstream populations (UN, 2010). Discharge of municipal wastewater and urban runoff into river basins have many detrimental effects on the water quality in these regions (Liyanage and Yamada, 2017).

Country-specific data on wastewater generation reveals that around 390 billion m^3 of wastewater is generated throughout the world (World Waterfall Database, 2017). However the amount of wastewater generated is projected to increase by 24% by 2030 and further about 51% by 2050 (Qadir *et al.,* 2020; Colella *et al.,* 2021). While compiling data on global wastewater generation and treatment, Sato *et al.* (2013) reported that highest quantity of wastewater is treated by high-income countries (70%), followed by upper-middle-income countries (38%), lower-middle-income countries (28%) and least (8%) by low-income countries. Sewage disposal is one of the major source of pollution of rivers in India (Suthar *et al.,* 2010). Several rivers of the country are severely affected due to disposal of untreated sewage (Guevart *et al.,* 2006; Gharbi-Khelifi *et al.,* 2007). Total sewage generation of the country is nearly 61754 MLD out of which treatment capacity exists for 22963 MLD leaving a gap of 38791 MLD. Central Pollution Control Board (CPCB, 2013) reported that out of 53,998 MLD of sewage generated about 19,827 MLD is treated in metropolitan (class one and two cities), however it also stated that only 13.5% of sewage is effectively treated out of 18.6% of total treatment capacity, (CPCB, 2013 and 2017).

Inland water bodies in Kashmir have offered a wide range of ecosystem services like water for irrigation and drinking purposes for the entire population (Dar *et al.,* 2020a; Yaseen and Bhat, 2021). Entry of untreated sewage is responsible for water quality deterioration of several lakes in Kashmir (Parvaiz and Bhat, 2014; Bhat and Pandit, 2014; Dar *et al*., 2020b; 2021 b,c,d) including Dal Lake, which has undergone remarkable changes in its chemical, biological and trophic status (Solim and Wanganeo, 2008; Vass *et al.,* 2015; Rashid *et al.,* 2017). In this context there was a necessity of treating the pollutants which are discharged into the lake. It was in this background that wastewater treatment plants (WWTP's) were established around Dal Lake at Hazratbal, Habbak and Laam (Wani *et al.,* 2013). Similarly, another two STP's were installed at Nigeen basin and Brari Nambal Lagoon of Dal Lake. Sewage generated within the city is diverted towards these treatment plants which discharge treated effluents into it. Dal Lake which is located in the North East of Srinagar city is of great ecological and economic importance. It serves as an important source of drinking water, irrigation and fisheries for the local population (Kawoosa, 2017; Nengroo *et al.,* 2017; Khanday *et al.,* 2018; Dar *et al.,* 2020b). It has been reported that the effluent discharges from STP's contribute to a significant pollution load of Dal Lake (Jan *et al.,* 2013; Qayoom *et al.,* 2021a). Partially disinfected sewage has adverse impacts on water quality of the lake thereby hampering its use for several purposes along with deterioration of economic services. This emerging scenario if allowed to remain for a longer period of time is surely going to change the lake characteristics which will defeat the purpose of having STP's around Dal Lake (Qayoom *et al.,* 2021b). Therefore, the main research question in this study was to evaluate the efficiency of these STP's in view of the recommended standards and to see to what extent they can be considered as useful and impactful in safeguarding the overall ecosystem health of Dal Lake.

STUDY AREA

FAB is a MBBR based attached growth technology used for treating wastewater where material (media) is used for the growth of microbes to increase the surface area for attachment (Pastorelli, 2000; Brinkley *et al.,* 2007; Biswas *et al.,* 2014). FAB technology is considered as an improved method for wastewater treatment than the conventional treatment systems due to less space, reduced power and operating costs and no sludge recycling. It consists of a bioreactor containing media made of suitable material and density. Movement of the media is attained by agitation produced during aeration or mechanical agitation (Leyva-Diaz *et al.,* 2017). The media range from plastic, high-density polyethylene, ceramic, glass, foam, peat, sand and gravel (Sonwani *et al.,* 2019). A biofilm of microbes is allowed to grow on suspended media inside the bioreactor which act upon the biodegradation of organics (Nageswara and Shruthi, 2002).

The present study was carried out on Hazratbal STP (34°08′06″N and 74°50′29″E) which is based on FAB technology. Its catchment area includes National Institute of Technology, Hazratbal, NaseemBagh, Kanitar, Saderibal and Umer colony. It has been constructed over an area of 1123sqm with the design capacity of 7.5 MLD. The Hydraulic retention time (HRT) of the STP is 3 to 4 hrs. The treatment in the STP is categorized into three distinct parts, pre-treatment, biological treatment and tertiary treatment. Apart from inlet and outlet, three stages within the STP where wastewater receives treatment were identified for collecting samples so as to provide an insight into its working and identifying the step at which problem in treatment of wastewater occurs (Fig.1).

I) Inlet

Sewage from connecting sewerage systems is directed towards STP which gets collected at the inlet or receiving sump of the plant. Inlet consists of 6 submersible pumps with each pump having a capacity of 196mt cub/hr. These pumps direct the wastewater from inlet towards the treatment systems. Inlet also consists of bar screen for the removal of various floating substances which are cleaned manually.

II) Fluidized Aerobic Bioreactor (FAB) I and II

These are two bioreactors in number which constitutes the biological treatment of the STP. Wastewater from inlet receives treatment initially in FAB I and then in FAB II where cylindrical particles made of plastic media are used for the growth and accumulation of biofilm within the reactors. The bioreactor tanks have a diameter of 7.75m^3 and a depth of 5m. Air is continuously fed to the reactors in order to prevent odor formation and also maintaining sufficient supply of oxygen to the microorganisms so that efficient break down of wastes takes place. The aeration capacity of the two FAB reactors is 650m^3 per hour by means of 2 blowers.

III) Clari tube settler

Treated water from FAB II is fed to claritube settler for the removal of readily settable solids which are later taken from the bottom of the settler and collected. Poly Aluminium Chloride (PAC) is added to wastewater prior to its entry in claritube. Here the removal of sludge from sewage takes place and water is prepared for addition of chlorine so as to remove pathogenic bacteria. Claritube settler tank has a depth of 5 feet.

IV) Outlet

Treated and disinfected water known as effluent is directed towards outlet from where it is discharged into Dal Lake.

Fig. 1. Map showing various stages of FAB based STP at Hazratbal near Dal Lake

MATERIAL AND METHODS

The present study was conducted in year 2015-16 in order to evaluate the efficiency of Hazratbal STP. A total of 20 sewage samples were collected over a period of four months (Jun-July, Jan-Feb) during early morning hours from 9:00 am to 10:00 am. Water samples at all the selected spots were collected at the sampling points in 1 liter polyethylene bottles and brought to laboratory.

The analysis was done as per standard methods are given in APHA (2005). In situ measurements of pH was carried out with a multi-parameter probe (Eutech PCSTEST35-01x441506) calibrated with standard solutions. Total Alkalinity (TA) (Phenolphthalein), Chloride (Cl^-) (Argentometric) and Dissolved Oxygen (DO) (Winkler Azide modification) were determined by titrimetric method. Parameters that were analyzed using Motras Scientific, UV Visible Spectrophotometer, include: Ammonical Nitrogen (NH_3-N) (Phenate method), Nitrate nitrogen (NO_3-N) (Salicylate method) and Total Phosphorus (TP) (Ascorbic acid method). COD was determined by Open reflux method while BOD was determined by 5 day incubation method and sewage dilutions at a ratio of 5:100 (5%) were prepared. Analysis of variance (ANOVA) was carried out using stastical software Minitab, version 18 in order to determine whether the difference among the groups of data are statistically significant or not.

Table 1. Mean values of physico-chemical features of raw sewage and effluent of three STP's in year 2010-12

Parameters	**Habak**		**Removal efficiency (%)**	**Hazratbal**		**Removal efficiency (%)**	**Laam**		**Removal efficiency (%)**
	Raw	**Effluent**		**Raw**	**Effluent**		**Raw**	**Effluent**	
pH	7.51	7.67	_	7.52	7.71	_	7.50	7.69	_
DO (mg/l)	1.53	4.11	_	1.4	4.39	_	1.41	4.56	_
TA (mg/L)	245	188	23	265	204	23	252	188	26
Cl^-(mg/L)	124	94	25	143	108	24	133	98	26
NO_3-N(µg/L)	2320	1891	19	2475	2089	16	2349	1936	18
TP (mg/l)	2.4	1.8	26	2.6	2	22	2.6	1.9	27
BOD (mg/L)	192	70	63	231	94	59	204	75	63
COD (mgO_2/L)	526	241	54	611	301	51	573	259	54

(Jan *et al.*, 2013)

Table 2. Results of various physico-chemical parameters of sewage at various stages of Hazratbal STP in year 2015-2016 along with discharge standard

Parameters	Months	Inlet	FAB I	FAB II	Claritube Settler	Outlet	ANOVA	Removal efficiency (%)	Indian Discharge Standards (EPA 2002)	USEPA (1994)
pH	**Jan-Feb**	5.2, 6.3	5.6, 6.5	5.6, 6.5	5.7, 6.6	6.7, 6.7	F=0.33; $P=0.854^{ns}$	_	**5-9.0**	**6.5–8.5**
	Jun-July	6.7, 6.1	6.8, 6.5	6.8, 6.6	6.8, 6.6	6.9, 6.7				
	Mean	**6.0±0.5**	**6.3±0.5**	**6.3±0.5**	**6.4±0.4**	**6.7±0.1**				
DO (mg L^{-1})	**Jan-Feb**	1.2, 1.2	3.4, 3.5	4.2,4.1	4.8, 5.4	5.7, 5.7	**F=6.64; P=0.003**	_	_	**6.0–9**
	Jun-July	2.1, 2.3	2.5, 2.3	2.3, 3.5	2.3, 4.4	3.5, 4.4				
	Mean	**2±0.47**	**3±0.58**	**4±0.77**	**4.2±1.05**	**5±0.92**				
TA (mg L^{-1})	**Jan-Feb**	237.2, 250	234, 228.1	222, 230	221.2, 220	142, 242	F=0.78; $P=0.555^{ns}$	**14**	**750**	_
	Jun-July	202, 252	197.2, 249.2	196, 245.2	185.2, 244	210, 216				
	Mean	**235.3±19.7**	**227.1±19.0**	**223.3±17.8**	**218±21**	**203±36.8**				
Cl^- (mg L^{-1})	**Jan-Feb**	27.2, 35.1	32.1, 34.1	30.1, 31.2	29, 29	25.1, 27	F=1.88; $P=0.167^{ns}$	**31**	**750**	**250**
	Jun-July	21.1, 35.2	20.4, 33.1	19, 27	18, 22.1	17, 18				
	Mean	**30±6.4**	**30±5.5**	**27±4.4**	**25±4.5**	**22±4.3**				
NO_3-N (µg L^{-1})	**Jan-Feb**	296, 688	299, 529	297, 410	198, 329	150, 259	**F=3.12; P=0.047**	**54**	**10,000**	_
	Jun-July	389, 375	259, 322	236, 245	219, 210	190, 200				
	Mean	**437±149.2**	**352±104.5**	**297±69.3**	**239±52.5**	**200±38.9**				
NH_3-N (mg L^{-1})	**Jan-Feb**	2, 4.1	4, 4	3, 3	2.3, 2	2, 2.3	**F=26.96; P=0.000**	**59**	**1**	_
	Jun-July	4, 5	4, 3.4	3, 3.2	3, 2.1	1.2, 1.3				
	Mean	**4.2±0.4**	**3.85±0.3**	**3.05±0.1**	**2.35±0.4**	**1.7±0.5**				
	Jan-Feb	2, 1.2	2, 1.2	2, 1.3	1.4, 1.1	1.2, 1.05	F=0.96;			

TP (mg L^{-1})	**Jun-July**	2, 3	2.3, 2	2.1, 2	2, 2	2, 1.4	P=0.460^{ns}	**27**	**1**	**_**
	Mean	**2.05±0.8**	**1.8±0.5**	**1.85±0.4**	**1.62±0.5**	**1.41±0.4**				
BOD (mg L^{-1})	**Jan-Feb**	66, 19.2	64, 72	50, 50	50, 50	76, 25	F=0.63; P=0.651^{ns}	**28**	**40**	**50**
	Jun-July	82.4, 83.2	52, 32	58, 47	51, 49	41, 38.4				
	Mean	**63±26.1**	**55±35.9**	**51±13.7**	**50±13.1**	**45±19.02**				
COD (mg O_2 L^{-1})	**Jan-Feb**	450, 422	425, 389	375, 325	288, 298	260, 252	**F=22.63; P=0.000**	**46**	**250**	**100**
	Jun-July	540, 476	459, 456	376, 350	250, 309	250, 264				
	Mean	**472±43.7**	**432±47.2**	**357±20.9**	**286±28.5**	**257±5.8**				

values in bold indicates significance; ns indicate non-significant

RESULTS AND DISCUSSION

The major findings of the earlier works carried out by Jan *et al.* (2013) on the efficiency of three FAB STP's installed around Dal Lake have been presented in table 1 and those of the present study on Hazratbal STP have been given in table 2. Parameters which are critical with regards to the working STP and those of the health of the receiving water body were targeted. There is a narrow range of pH suitable for the survival of most biological life forms and is typically between 6 - 9.5 (Vajja and Krishnarao, 2020). Values of pH in the raw wastewater are mostly acidic due to the decomposition of organic matter in waste stream (Choksi *et al.,* 2015; Florence *et al.,* 2020) releasing hydrogen ions that are associated with organic anions lowering the pH (Porter *et al.,* 1980). In the present study, mean values of pH in the raw (6.0±0.5) were slightly more acidic as compared to the final effluent (6.7±0.1), which was due to the reduction of free carbon dioxide level in the final effluent. Moreover, addition of PAC also caused shift in the values of pH (Jan *et al.,* 2013). A similar trend was also reported by Hadji *et al.* (2020) in the WWTP of Algeria. However, mean values of pH in the effluent were within the Indian (5-9) as well as USEPA (6.5 - 8.5) discharge standards thereby posing no threat to the aquatic life of the receiving water body.

Dissolved oxygen is an important parameter for estimating the pollution level due to organic matter and determines physical as well as biological activities like decomposition of organics in water (Agoro *et al.,* 2018). Due to prevailing septic conditions, high organic load (Prescott *et al.,* 2002) and flow of sewage through closed sewer lines resulted in low DO conditions in the raw (Awuah and Abrokwah, 2008). There was significant variation ($P<0.05$) in the DO of raw (2±0.47mg/l) and effluent (5±0.92mg/l) which increased during treatment due to aeration process taking place in the bioreactors resulting in stabilization of organics. Aquatic life has an acceptable DO standard of 4–5 mg/L (Agoro *et al.,* 2018) while the concentration of DO in the effluent was much below the recommended limits of USEPA (6-9mg/l), thus posing potential danger to receiving water body (Olabode *et al.,* 2020). Oxygen demanding wastes result in the deterioration of DO levels which effect both water quality as well as biodiversity (Suthar *et al.,* 2010). Further, low concentration of dissolved oxygen increases the toxicity of certain substances which pose threat to various forms of aquatic life (Osuolale and Okoh, 2015). In the present study BOD_5 in the influent (63±26.1mg/l) was contributed from domestic wastes effluents from households. Organic matter present in the waste is oxidized by microbes present in the bioreactor resulting in decrease in BOD apart from coagulation and flocculation taking in the Claritube Settler (Jan *et al.,* 2013). Stage wise evaluation also revealed a gradual decreased in BOD of the effluent (45±19.02mg/l) as the sewage was subjected through aeration in FAB I and II. Previous study has reported BOD removal efficiency of 59-63% for Hazratbal, Habbak and Laam STPs which reflects a major deviation as our results of BOD indicates only 28% removal efficiency with insignificant variation

(P>0.05) during treatment. Values of BOD_5 in the effluent was exceeding the Indian (40mg/l) and USEPA (50mg/L) discharge standard. Effluents with high values of BOD can exert oxygen demand and increase bacterial growth in the receiving water body (Adbarzi *et al.,* 2020). COD in wastewater is due to organic as well as inorganic compounds in the wastewater representing oxygen depleted per liter (Faisal *et al.,* 2020). Values of COD in the raw (472±43.7mgO_2/l) were higher than BOD which is an indication of the presence of some amount of inorganic substances in the domestic wastewaters. However, its reduction in the effluent (257±5.8mgO_2/l) could be attributed to the aeration and decomposition process taking place during treatment with significant variation (P<0.05). Removal efficiency of 51-54% in the previous study did not reflect much deviation of our results which turn out to be 46%. COD values in the effluent were higher than recommended values of CPCB (250mgO_2/L) as well as USEPA (100 mgO_2/L). The high concentration of oxygen demanding wastes in the effluent can increase the organic loading in the lake which will deplete the oxygen concentration of receiving waters and eventually impact aquatic life. High values of NH_3-N in the influent (4.2±0.48mg/l) may be due to higher resident time in the sewer due to which most of the nitrogen gets converted into NH_3-N (Mahapatra *et al.,* 2013). NH_3-N which is considered a toxic substance for fish and other aquatic life exhibited a removal efficiency of 59%. Values of NH_3-N in the effluent (1.7±0.53mg/l) were exceeding the Indian discharge standards (1mg/l). It showed significant variation (P<0.05) in the effluent and the reduction may be due to the increased rate of nitrification caused by micro-organisms under aerobic conditions (Gamble, 1999; Drewnowski *et al.,* 2021). NO_3-N is an important nutrient in waste effluents which not only accelerates the eutrophication process in fresh water ecosystems (Fried, 1991) but also poses heath risk to infants (Bush and Meyer, 1982) and thus remains an ecological and health concern. The removal efficiency of NO_3-N was 54% in the present study which is higher than previous work which ranged only between 16-18%. The discharge standards of nitrate was below recommended standards (10,000µg/l) and thus not pose serious ecological health concerns. Phosphates in sewage is added from human wastes, detergents and soaps (Ogunfowokan *et al.,* 2005) and is a limiting nutrient making phosphorus regulation important in STP's (Mahapatra *et al.,* 2013). Phosphorus is considered as the main limiting nutrient responsible for eutrophication apart from other adverse ecological effects (Lewis *et al.,* 2011). Phosphorous removal efficiency of Hazratbal STP was only 20% which was in conformity with previous work where an efficiency of 22 to 27% was reported. Phosphorus removal mechanism in the treatment facilities is attributed to both biological and chemical treatments like assimilation, adsorption and precipitation (Rajeb *et al.,* 2011). Besides, tertiary treatment systems in said STP is designed to remove nutrients such as Nitrogen and Phosphorus (Jan *et al.,* 2013) which includes use of chemicals like PAC acting as a coagulant, (Hammer, 2013) prior to the entry of sewage into Claritube Settler. Surprisingly the concentration of phosphorous subjected to the treatment of PAC in the treatment facility did not yield the desired results. The possible problem is actually right type of dosage of PAC for complete precipitation of phosphorus from the sewage. Concentration of phosphorus in the effluent were exceeding the Indian discharge standards (1mg/L).

Insignificant reduction was observed in parameters like TA and Cl^-. The design of FAB technology is based on the principle that will take care of the oxidation/stabilization of the organics and also the removal of phosphorous and nitrogen. Therefore, these parameters remain almost largely unaffected while passing from inlet to outlet in the treatment facilities.

CONCLUSION

It was observed that the effluent concentrations for BOD, COD, ammonical nitrogen and phosphorus were not meeting the discharge standards. Phosphorus being limited nutrient in freshwater systems have the potential to cause havoc in the form of eutrophication, which needs a regular monitoring. Overall most of the parameters witnessed low removal efficiency which remains a concern. Keeping in view the significance of these treatment systems in maintaining the health of Dal Lake it becomes necessary to monitor the effluents and suggest remedial measures thereof. It is also desirable to have a technically sound as well as skilled manpower for operation and maintenance of STPs and constructive wetlands for tertiary treatment before the water is directly discharged into Dal Lake. Other priority for the LCMA (Lake Conservation and Management Authority) issues connected with STPs and lake ecology is connecting the sewage of House boats and unattended portion of sewage from the catchment to STP that will supplement the management efforts of LCMA. Low temperatures here in Kashmir are also contributing to poor efficiency of STPs.

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