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DUAL-MEDIA GRANULAR FILTRATION SYSTEM FOR SLAUGHTERHOUSE WASTEWATER TREATMENT: A CASE STUDY IN BANGLADESH

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ABSTRACT

In developing countries, including Bangladesh, deliberate disposal of the untreated slaughterhouse wastewater causes environmental pollution and poses threat to public health. In this study, slaughterhouse wastewater was analyzed for the Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD_5), and faecal coliforms (E. coli) were found ranging between 1,840–3,300 mg/L, 62–619 mg/L and est.>3,400–6,00,000 CFU/100 ml, respectively. A bench-scale treatment unit, adopting activated sludge process, was developed in the laboratory and the average treatment efficiency for BOD_5 and TSS were found 67% and 39%, respectively. However, the efficiency for microbial removal performance was inconclusive. An additional duel-media granular filtration unit was developed to improve the effluent quality and the treatment efficiencies for BOD_5, TSS and E. coli were improved to 90% to 100%. The study highlighted the level of pollution caused by the slaughterhouse wastewater disposal to the surrounding water bodies and how the decentralized treatment approach can improve water quality.

Keywords: *Activated sludge, Pollution, Public health, Slaughterhouse wastewater, Sustainability, Treatment.*

1. INTRODUCTION

Urbanization is ever existing dimension of anthropology and eventually this trend is particularly high in developing countries. The extensive urbanization takes place mainly in smaller urban centers and peri-urban developments, which mostly is unplanned and informal. The developed part of the developing country like Bangladesh is even built in a piecemeal fashion. Rapid industrial development is a crucial part of advancement as improper planning may lead to environmental damage. Global health, population growth, economic development, environmental degradation and climate change are the main challenges currently Bangladesh is dealing with. For high population density and careless construction of commercial areas, the distress becomes multidimensional. Slaughterhouse wastewater management is one of these problems, which mainly is produced from the commercial areas referring slaughterhouses, chicken and fish slaughtering and processing unit and disposed nearby watersheds carelessly (Pozo et al., 2003).

Due to huge population, unemployment problem, lack of public awareness and mostly ignorance of the administration bodies about well-planned slaughterhouse infrastructures, the wastewater generated from the shops pollutes almost all watercourses of Bangladesh. In developed countries, the slaughterhouses are built with self-sufficient facilities and treatment plants (Gardner & Örmeci, 2010), whereas in Bangladesh, the local shops offer some extra spaces for slaughtering animals instead of separate slaughterhouses. Wastewater produced from slaughter-sections in addition to wastewater generated from the shops disposed to nearby watersheds through canals and open channels that contains highly contaminated animal body fluid, blood, worms, bacteria and viruses (Emmanuel et al., 2016). Health hazard increases due to exposure to the contiguous pathogens and degraded physico-chemical characteristics of the effluent, leaving the children in greater risks. However, depending on the type of waterborne disease and physical health condition of the concerned individual, the person may either recover completely or suffer permanently from the resultant disease (Ebong et al., 2020). Furthermore, disposal of incorrectly treated effluent often results in an increased number of microbial pathogens which may lead to waterborne diseases (Chigor et al., 2012). Often, the slaughterhouse effluent causes algal blooms in the watersheds, damage the aesthetic of recreational water lagoons and limits property values. These environmental factors place even further stress on the deteriorating water and sanitation infrastructures, more so in developing regions, where millions are still at risk of Water, Sanitation and Hygiene related diseases (Wahyuni, 2015). The deficiency of basic facilities, services, and efficient methods for controlling

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slaughterhouse wastewater has led to widespread fouling of surface as well as groundwater and aggravated aquatic ecology and environment. Hence, slaughterhouse wastewater should be treated prior to disposal with a view to reducing the negative impacts on human health and environment (Truu et al., 2005).

Decentralized treatment facilities could be effective in context of Bangladesh as no central wastewater collection system presents in most cities. A physical treatment process followed by chemical and biological purification methods are commonly adopted to remove suspended solids along with the organic substances and toxic pathogens from slaughterhouse wastewater (Bartram & Pedley, 1996) even though the specific treatment process should be selected based on the type, degree of contamination and disposal location. For this study, the experiment was conducted based on the typical wastewater generation and disposal system in Bangladesh as this is almost similar in all cities. Primarily, the authors wanted to conduct surveys to determine the physical, chemical/biochemical and microbial characteristics of slaughterhouse wastewater and treat it with activated sludge process and hence, to check the pollutant removal efficiency. As, the slaughterhouse wastewater was heavily polluted, even with a good removal performance of the treatment unit operated with activated sludge process, the authors developed an additional tertiary treatment procedure which raised the removal performance to higher degree.

Therefore, the specific objectives of this study are to develop a small-scale treatment unit for the slaughterhouse wastewater; to assess its removal performance and recommend further treatment approach, if necessary. It is also expected that the outcome of this study will create awareness of the consequences of improper management, and deliberate disposal of the abattoir/market wastewater in water bodies without any treatment.

2. MATERIALS AND METHODS

2.1 The study area and sampling site

Detailed field survey was carried out in various meat processing sections in local shops in Khulna metropolitan area (22°49′N, 89°33′E), Bangladesh (Figure 1).

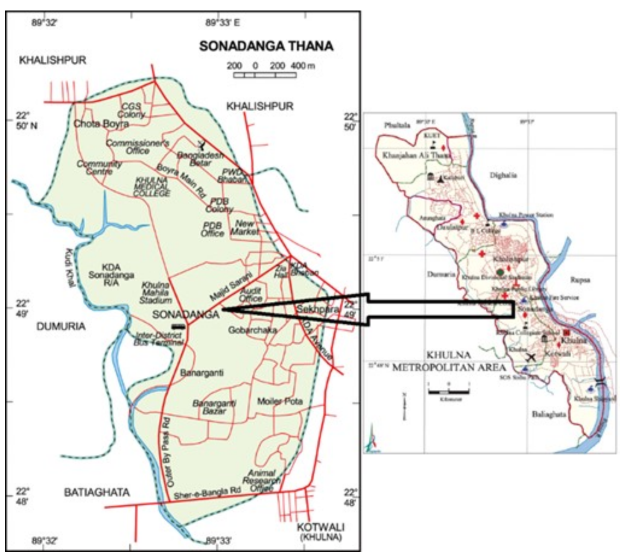

Figure 1: Location of the Study Area.

Wastewater produced from slaughter-section in Gollamari market was approximately 40,000 L per day that was disposed to nearby Moyur River by open canals and local drains. First batch of water samples collected from this site mostly contained animal blood and body fluid diluted with tap water. The second and fourth batch of water samples were collected from the fish market that contained mostly body fluid of fishes. The third batch of water samples were collected from an open canal that combined wastewater generated from fish market and vegetable market and eventually, carried the wastewater to nearby watersheds. The sample contained mostly debris from vegetables and body fluid of fish. Table 1 summarizes the samples used for the development of the treatment unit and Figure 2 shows the sources of the collected samples.

Table 1: Locations of Collected Samples and Physical Components of the Influents.

Samples	Locations	Major components of influent
Sample 1	Gollamari market, Khulna	Diluted blood, body fluids, liquid gut content
Sample 2	Banargati market, Khulna	Body fluids from fish
Sample 3	Nirala market, Khulna	Body fluids from fish and vegetable debris
Sample 4	Banargati market, Khulna	Body fluids from fish

Figure 2: The Source of Water Samples Collected for the Experiments. The Top Left Corner Image Shows Source of Sample 1, Bottom Image Shows Source of Sample 2 and 4, and Top Right Corner Shows Source of Sample 3.

2.2 Water sample collection and water quality analyses

Water sample collection and water quality analyses: To characterize the slaughterhouse wastewater, 'grab samples' were collected from the point sources (Simpson 2013) and analyzed for organic contaminants, nutrients, metals and pathogens following the Standard Methods (SM) of Analysis (APHA 1998). Polyethylene sampling bottles (150 mL) were used for collecting the water samples. All samples were sealed tightly to prevent contamination, stored on ice, and sent for analysis within 2-3 hours of sampling.

Collected water samples were analyzed for biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total solids (TS), total suspended solids (TSS), total volatile solids (TVS), volatile suspended solids (VSS), alkalinity, electrical conductivity (EC), total coliforms, *E. coli.*, nitrate-nitrogen (NO3-N), phosphate (PO4), and iron (Fe). The BOD5 was measured using BOD bottle, dissolved oxygen meter (HACH, HQ 40d) and incubator (VELP SCEINTIFICA, FTC 90E); COD was measured using COD vial and COD reactor; TS, TSS, TVS and VSS were measured using evaporating dish, digital balance (OHAUS, adventure, readability 0.000), thermostatic water bath, oven (HERAEUS), desiccator, filter paper, filtration apparatus or suction apparatus (SARTORIUS); EC using conductivity meter (HACH, sension156); number of coliforms and Escherichia coli was measures with filtered diluted samples using cellulose nitrate filter using filtration apparatus and incubator (GENLAB, mini/30/DD). NO3-N, PO4, and Fe were measured on a spectrophotometer (HACH, DR 2700) using standard test kits.

2.3 Design of the process variables and construction of the activated sludge treatment unit

Design criteria for the activated sludge process variables were developed after taken the laboratory investigated physical, chemical and microbial characteristics of the slaughterhouse wastewater into consideration (Mara 2004). A bench-scale treatment system was constructed with a primary clarifier chamber, the reactor or aeration tank chamber with an aeration pump, the settling tank or secondary clarifier chamber with a pump for returning sludge and a final chamber for storing treated water. High quality Polyethylene containers of same dimensions were used as the activated sludge treatment chambers (Figure 3).

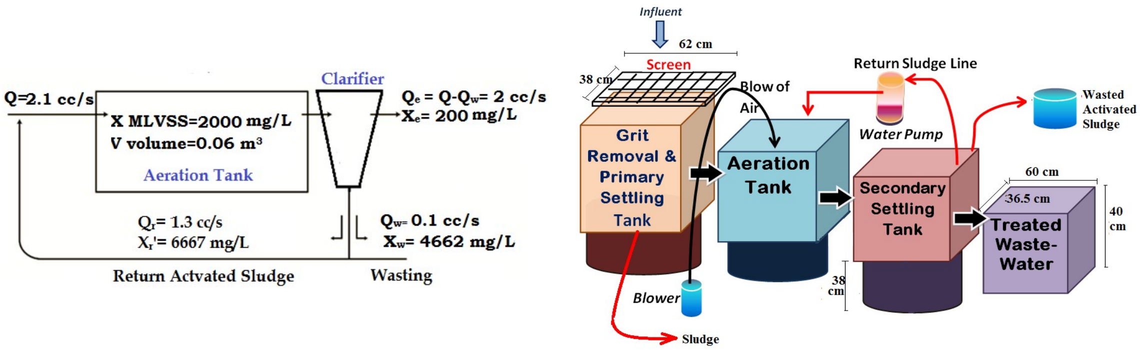

Figure 3: Process Variables (left) and Schematics (right) of Activated Sludge Treatment Unit.

The activated sludge process was designed using empirical formula stated below:

For calculation of mean cell residence time,

$$\theta c = \frac{VX}{Q_w X_r + (Q - Q_w) X_e} \quad (1)$$

hydraulic retention time or volumetric loading,

$$\theta = V/Q \times 24 \quad (2)$$

$$\text{the F/M ratio} = QS_o/VX \quad (3)$$

wasting flow rate for sludge,

$$Q_w = VX/\theta_c * X_r \quad (4)$$

return sludge flow rate,

$$Q_r = \{QX' - Q_w X_r' - (Q - Q_w) X_e\}/(X_r' - X') \quad (5)$$

Where, Q, Q_r and Q_w : influent, return sludge and wasting flow rate

X, X_r' and X_r : influent, return sludge and wasting volatile suspended solids (VSS);

X' : mixed liquor suspended solids (MLSS),

V: volume of reactor (Davis, 2013).

The slaughterhouse wastewater influent was primarily filtered (0.25 cm x 0.25 cm) through and settled in the grit chamber or the primary clarifier which then carried to the aeration tank with a flow rate of $2.1*10^{-6}$ m^3/s. The estimated hydraulic retention time for aeration tank was 4 hours where the wastewater was aerated sending to the next chamber. After thoroughly aerated the wastewater in the aeration tank, it was carried to the secondary clarifier for bacterial floc formation and settlement of the activated sludge or the biomass. From the bottom of the secondary clarifier, the settled sludge was pumped (also known as the return sludge line) with a flow rate of $1.3*10^{-6}$ m^3/s to the aeration chamber to maintain the food to biomass ratio (0.93 mg/mg day^{-1}). A wasted sludge line with a flow rate of $0.1*10^{-6}$ m^3/s was maintained to withdraw settled sludge from secondary clarifier chamber to operate the activated sludge process properly. Finally, the treated water effluent was collected in treated wastewater chamber (Figure 3) and water samples were collected for laboratory analyses to check the treatment efficiency. The mean cell residence time or the total run time for the whole process was approximately 96 hours. Figure 4 shows the laboratory set up of the bench-scale activated sludge treatment unit.

Figure 4: Laboratory Setup of Activated Sludge Treatment Unit.

2.4 Design and construction of the duel-media filtration unit

Mix extended modified duel-media filtration unit was constructed with locally available, pre-washed brick-chips (dia <10 mm) bed at the bottom along with sand (dia <1 mm) bed on top, uniformly distributed with 5 cm height (Figure). The treated wastewater effluent travelled through the brick-chips bed followed by sand bed forming an upward flow within the chamber. The slaughterhouse wastewater from the fish processing section of Banrgati market was treated with the activated sludge treatment unit followed by biologically treated with duel-media filtration unit. The wastewater was passed slowly through the media where at the top the microbial community or the schumtzdecke treated the wastewater. The treated wastewater was collected from the activated sludge treatment unit as well as afterwards from the up flow filtration unit and analyzed for the same water quality parameters to check and compare the treatment efficiencies.
Figure shows the image of the bench-scale upgraded duel-media granular filtration unit.

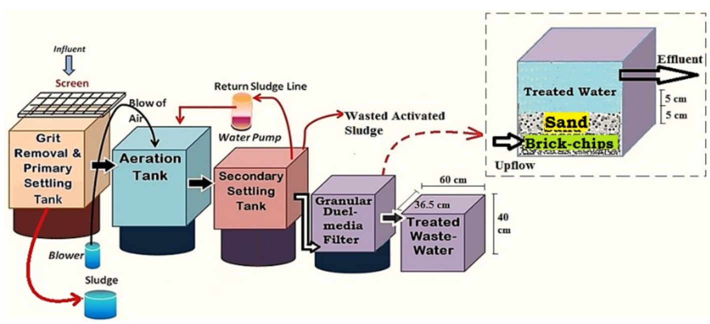

Figure 5: Schematics of the Upgraded Duel-Media Granular Filtration Unit.

Figure 6: The Developed Upgraded Duel-Media Filtration Unit.

3. RESULTS AND DISCUSSION

3.1 Efficiency of the activated sludge treatment unit

The physical, biochemical/chemical and microbial properties of the slaughterhouse wastewater and the treated effluent found from the laboratory analyses are presented in Table 2 and Table 3, respectively. As, there is no set standard for disposal of slaughterhouse wastewater in inland water bodies in Bangladesh, alternatively, for this study, the authors considered the standard limits for industrial effluent wastewater disposal into inland water bodies (Government of the People's Republic of Bangladesh & Ministry of Environment and Forest, 1997) (in these tables it is represented as *ECR'97 discharge standards). Even though some of the final water quality parameters did not fulfil the criteria for safe disposal into inland water bodies, all but the microbial water quality improved after treatment.

Table 2: Water Quality Test Results of Slaughterhouse Wastewater Samples.

Water Quality Parameters	Unit	Influent market wastewater				*ECR'97 discharge standards
		Sample 1 (Gollamari market)	Sample 2 (Banaragti market)	Sample 3 (Nirala market)	Sample 4 (Banaragti market)	
Biochemical Oxygen Demand (BOD_5)	mg/L	619	141	62	41	50
Chemical Oxygen Demand (COD)	mg/L	960	380	160	105	200
Total Suspended Solids	mg/L	3300	3040	1840	2120	150
Volatile Suspended Solids	mg/L	1960	1580	1280	640	-
Electrical Conductivity	mS/cm	66.7	1.6	3.9	4	1.2
Iron (Fe)	mg/L	35	4.5	21	2.4	2
Nitrate (NO_3-N)	mg/L	1020	9	24	6	10
Phosphate (PO_4)	mg/L	4510	178	40	20.8	-
Total Coliform	N/100 mL	600000	6000	3840	48600	-
E. coli	N/100 mL	280000	2000	1800	300	-

The market wastewater samples showed high concentration of BOD_5, suspended solids along with nutrients. Often, the high organic pollutants for the abattoirs come from the animal blood and gut content which causes excessive BOD_5 and COD (Pozo, Taş, Dulkadiroğlu, Orhon, & Diez, 2003). After treatment in the activated sludge treatment unit, the average BOD_5 and COD removal efficiencies were found to be 67±9% and 51±13%, respectively (Figure 7). Pozo et al. (2003) concluded that lower BOD_5/COD ratio occurs when abattoir wastewater have higher blood content. This finding contradicted with our findings but on the other hand, it matched with the results of Emmanuel et al. (2016); as the BOD_5/COD ratio for sample 1 (higher blood content) was higher (0.64) than the other samples (0.39, on average).

Table 3: Water Quality Test Results of the Corresponding Treated Effluents.

Water Quality Parameters	Unit	Treated market wastewater				*ECR'97 discharge standards
		Sample 1 (Gollamari market)	Sample 2 (Banaragti market)	Sample 3 (Nirala market)	Sample 4 (Banaragti market)	
Biochemical Oxygen Demand (BOD_5)	mg/L	124	59	17	17	50

Water Quality Parameters	Unit	Treated market wastewater				*ECR'97 discharge standards
		Sample 1 (Gollamari market)	Sample 2 (Banaragti market)	Sample 3 (Nirala market)	Sample 4 (Banaragti market)	
Chemical Oxygen Demand (COD)	mg/L	320	160	110	55	200
Total Suspended Solids	mg/L	2800	900	760	1900	150
Volatile Suspended Solids	mg/L	890	780	320	580	-
Electrical Conductivity	mS/cm	5.7	1.5	3.7	3.3	1.2
Iron (Fe)	mg/L	22	2.7	0.8	1	2
Nitrate (NO_3-N)	mg/L	110	6	3	4	10
Phosphate (PO_4)	mg/L	626	46.8	2.4	6.6	-
Total Coliform	N/100 mL	700000	28500	2740	174000	-
E. coli	N/100 mL	400000	18900	2570	7500	-

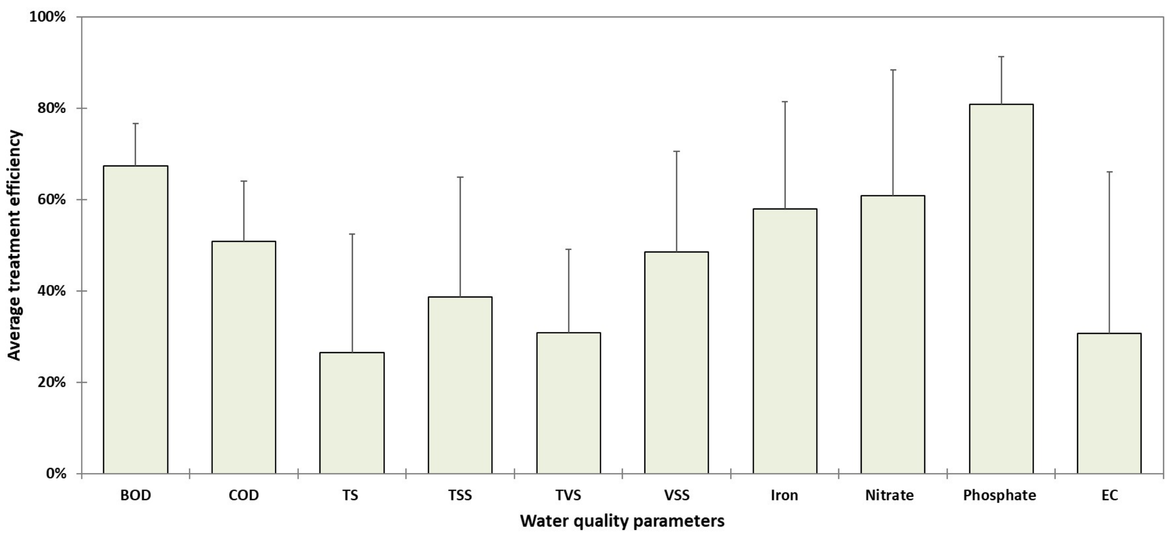

Figure 7: Average Treatment Efficiencies in the Developed Activated Sludge Treatment Unit.

Generally, the BOD_5 values along with the level of total dissolved solids (TDS) and total suspended solids (TSS) indicate the extent of organic pollution in any aquatic system (Jonnalagadda & Mhere, 2001). The activated sludge treatment unit removed total and volatile suspended solids around 40% on average by settling the sludge formed in microbial activity. Direct disposal of untreated wastewater with animal blood, body fluid and natural debris generated in abattoirs containing large concentration of biodegradable wastes, solids along with nitrogen and phosphorus cause algal bloom in watersheds that adversely affect ecosystem by reducing its dissolved oxygen content (Chigor et al. 2012; Ebong et al. 2020). However, phosphate alone does not have any significant harmful health effects except for contributing to eutrophication and toxic algal blooms (World Health Organization, 2008).

As, Emmanuel et al. (2016) explained that the blood and gut contents contributed in increasing nitrogen and phosphorus in wastewater, we also found the similar trend in our experiment. Sample 1 enriched in blood and gut fluid contained high concentration of nitrate and phosphate compared to other three samples (data not shown). The average treatment efficiencies of nitrate and phosphate in activated sludge treatment unit were 61±28% and 81±10%, respectively. Along with the nitrate and phosphate reduction, the conductivity and alkalinity also dropped as a result of the removal of the total dissolved solids and other ionized species in the effluent (World Health Organization, 2008). However, no specific pattern or relationship was observed between the conductivity and total dissolved solids as explained by Emmanuel et al. (2016) in their research.

We agree with Chigor et al. (2012) in not noticing any particular correlation between water temperature and faecal coliform counts during the treatment in the activated sludge treatment chambers but, we also did not see any positive correlation between BOD_5 and faecal coliform as they mentioned. The faecal coliforms increased after treatment which happened possibly as a mutual effect of favorable water temperature (Bartram & Pedley, 1996; Gardner & Örmeci, 2010) and slightly alkaline nature of the water (Wahyuni, 2015). In the duel-media disinfection unit, the number of *E. coli* became nil and the total coliform reduced 98% (Table 4). The degree of removal of the faecal coliform for this particular sample (sample 4) could be a combined effect of a reduced water temperature (almost 10º C lower than the previous three samples) and additional biological treatment in the duel-media treatment unit. Even though a higher temperature could be beneficial for the nutrient and total dissolved solids removal by speeding up the chemical reactions but it can be disadvantageous for pathogen treatment (Jonnalagadda & Mhere, 2001). The pathogen count of the effluent might increase for another reason which is a slightly higher pH of the effluent. The effluent pH increased after treatment although it remained within the standard limits. The trend of increasing pH in treated wastewater might be a result of CO_2-freed air (as due to continuous air flow, the CO_2 striped out of the system) which has the potential to increase the pH of wastewater to a slightly higher level (Cohen & Kirchmann, 2004).

Table 4: The Number of Faecal Coliforms found in Influent (Raw), Treated Effluent (Activated Sludge Process) and Treated Effluent (Disinfection Unit).

Sample	Average water Temperature (ºC)	Aver-age pH	Total coliform (CFU/100 mL)			*E. coli* (CFU/100 mL)		
			Raw	Treated (activated sludge)	Disinfected	Raw	Treated (activated sludge)	Disinfected
1	28±1.0	8±0.4	est> 600000	est> 700000	-	est> 280000	est> 400000	-
2			6000	est> 28500	-	2000	est> 18900	-
3			3840	2740	-	1800	2570	-
4	20±0.7	7.5	est> 48600	est> 174000	750	300	est> 7500	0

The overall performance of the activated sludge treatment unit was good as the organic loading and nutrient removal efficiency was 50% or more, in average. But since the influent nutrient concentration was strong, the effluent disposal concentration for several parameters exceeded the standard limit (Government of the People's Republic of Bangladesh & Ministry of Environment and Forest, 1997), the additional duel-media filter was introduced to check the improvement of removal performance.

3.2 Efficiency of the duel-media granular filtration unit

The results of water quality analyses from the activated sludge treatment unit and then up-flow filter unit showed further improvement of the water quality after treating it in duel-media granular filter, except for nitrate, phosphate and iron (
Figure). A possible reason for increased phosphate and iron in the effluent only in the up-flow filter unit could be that, these nutrients leached (Lahmann & Schroth, 2003) from the granular media. The organic and inorganic oxygen demand reduced further 20% while the solid particles were removed further 70% in the disinfection unit compared to the reduction in activated sludge treatment unit alone. The increased pathogenic removal performance (as discussed in previous section) could be a function of the up-flow filtration technique that increased the time of filtration and reduced substantial time for backwashing (Zouboulis, Traskas, & Samaras, 2007), leaving more scope to pathogen-schumtzdecke interaction for improved efficiency. Along with the mechanical filtration process, the biological treatment took place as well in the duel-media filter bed where the schumtzdecke (Huisman & Wood, 1974) formed and broke up organic matters for the protozoa and metazoa along with other group of microorganisms (Truu, Nurk, Juhanson, & Mander, 2005) to consume and keep the bed clean and functional (Calaway, 1957).

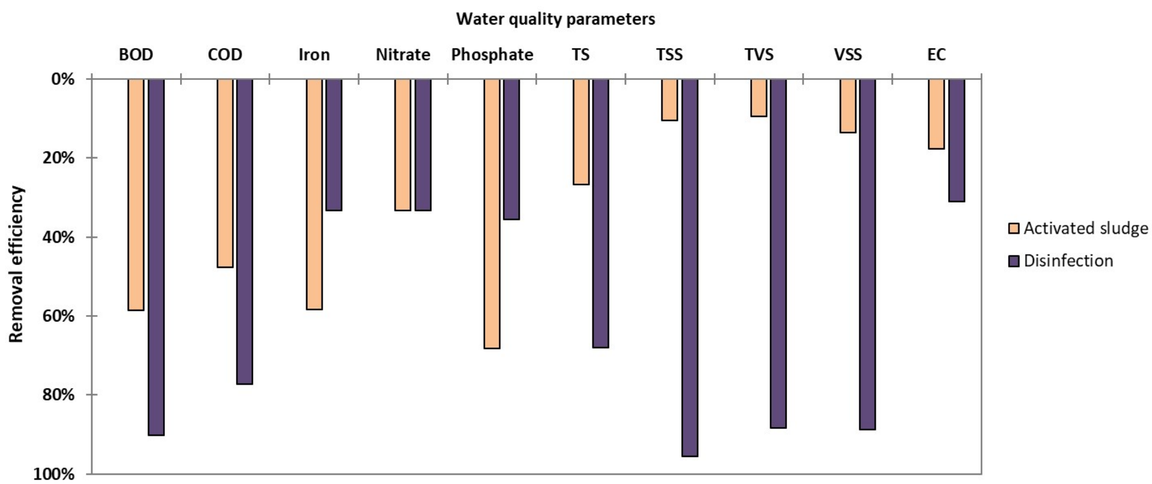

Figure 8: Comparative Chart of the Removal Efficiencies in Activated Sludge Treatment Unit Followed by Up-Flow Duel-Media Granular Filter Unit.

The effluent water quality overall improved and fulfilled the standard for effluent disposal into inland water bodies after treating it with up-flow duel-media granular filter unit (Government of the People's Republic of Bangladesh & Ministry of Environment and Forest, 1997). Treatment with activated sludge process removed sediments and nutrients followed by duel-media granular filtration would be beneficial for a long term operation and maintenance. Moreover, these two biological treatment methods could be operated by slaughterhouse workers with some basic trainings that do not require high skill level, compared to other treatment methods like trickling filter or membrane treatment technologies. In Bangladesh, these two consecutive water treatment technics could reduce inland water pollution level, if adopted and practiced.

4. CONCLUSIONS

This study reveals that the general practice in Bangladesh for slaughterhouse effluent disposal to nearby water bodies is one of the major causes for river water pollution and ecological disaster. The physicochemical characteristics of the slaughterhouse wastewater exhibit intense nature of nutrients and pollutants which do not meet the permissible limits of the National Standards (Government of the People's Republic of Bangladesh & Ministry of Environment and Forest, 1997), and therefore not appropriate for direct disposal into water bodies. It is therefore recommended to adopt a treatment technology to decrease the impact on human health and aquatic ecosystem and environment. Application of our developed treatment technologies with activated sludge process followed by duel-media granular filtration system could reduce the biodegradable organics, pathogens, nutrients significantly, and improve the effluent water quality to prevent eutrophication as well as increase aquatic oxygen supply. Implementation guidelines could be adopted for different slaughterhouses country-wide to reduce the pollution where Government could also participate in facilitating wastewater treatment plant installation with technological and monetary support. A methodology could be adopted by encouraging planned slaughterhouse construction with treatment facilities as well as by applying penalty cost where necessary (Mahjoobi, Sarang, & Ardestani, 2016). In the long run, the effectiveness of wastewater treatment plant installation can only be established by proper surveillance and an enforcement of strict environmental management by regulatory authorities to solve the burning issue like environmental conservation. Further research could also be carried out in future to upgrade and adapt new features (Dalahmeh et al., 2012) for further improvement.

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