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DESIGN AND PERFORMANCE ANALYSIS OF A BENCH SCALE BIOLOGICAL WASTEWATER TREATMENT PLANT FOR A SHRIMP PROCESSING INDUSTRIY IN THE KHULNA DISTRICT OF BANGLADESH

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ABSTRACT

In Bangladesh, most of the shrimp farming and industries are situated in the southwestern region. One ground survey has estimated that effluents of 47500 L/day/plant generated are directly released in the environment in the Khulna region. The effluent of shrimp process industry of the study area contains typically in average DO of ±2 mg/L, TDS of ±2894 mg/L, TSS of ±385 mg/L, BOD of ±177mg/L, and COD of ±355 mg/L. This study has been performed to find the solids removal rate and whether the extended aeration activated sludge process can meet the national standard in the study area. Based on the raw wastewater parameters, a bench-scale biological treatment plant has been designed, operated and analyzed and it was set up in the Civil Engineering building of KUET. A circular type clarifier with a rectangular aeration basin has been designed. Diffused air has been provided in the aeration tank of the bench-scale plant. Maintained a constant wastewater flow (20 ml/min) during the study period. The result has shown, the bench-scale biological treatment plant has been removed remarkable organic load from wastewater of the shrimp processing industry. The BOD and COD measured more or less 50 mg/L and 120 mg/L after treatment. The Total Dissolved Solids of effluent has been found on average 1805 mg/L. The removal rate of BOD_5 and COD has been calculated 77% and 67% respectively. The Total Suspended Solid was found 383 mg/L in raw wastewater and after treatment, it was measured 137 mg/L. The Dissolved Solid removes from 2894 mg/L to 1805 mg/L. Therefore, the designed bench-scale biological treatment method can be a solution for the wastewater treatment of the existing shrimp process factories in the study area.

Keywords: *Shrimp process wastewater; Activated sludge process; BOD; COD*

1. INTRODUCTION

There are 162 fish processing plants in the country among 96 are GoB licensed (Kabir, 2014) and most of them situated in Khulna and nearby. A ground survey has measured 47,500 L/day/plant wastewater generated and directly released in the environment (Billah, 2016). Therefore, the environment is polluting by shrimp processing wastewater. In 1960s shrimp culture has started from the coastal Satkhira district. Gradually, it has expanded to the other coastal belts of Khulna, Bagerhat, Cox's Bazar and Chattogram (Naureen *et al.,* 2006). It earns US$ 526.45 million in 2016-17 fiscal years (BFFEA, 2006). It has a great contribution to the national economy of Bangladesh, contrary inverse impact in the environment. It contains an objectionable level of pollutants. Mainly, organic loading is found higher in shrimp processing industries wastewater. Different experiments have found different inorganic and organic value of shrimp processed wastewater. A study on seafood (shrimp processing) industries wastewater of Khulna has shown effluents contains pH of 8.06±1.12, DO of 7±0.12 mg/L, TDS of 1777±553 mg/L, TSS of 543±187 mg/L, BOD of 377±15 mg/L, COD of 593±10 mg/L (Billah, 2016).

There are very few shrimp processing industries in the study area that have their wastewater treatment plant and one site inspection has found it does not operate properly. Inspection also has given information that there was no special design provided by vendors or consultants. Nowadays, there are many biological treatments is being used in Bangladesh. Some of them need long mean cell residence time some of which need excess aeration. Conventional suspended growth activated sludge process can be used for mid-level wastewater. It involves 5 to 15 days for mean cell residence time (Daniel, 2013). Conventional or existing design for the shrimp process wastewater treatment is chemical-based and thus it is costly. In this study, no chemicals were used in the operation of the bench-scale biological wastewater treatment plant and obtained good results.

This study has been done to determine the solids removal rate by analyzing the result after the installation and operation of a bench-scale plant. Design the best possible biological wastewater treatment plant and determine the initial characteristics of a seafood processing industry were the main goal of the study. There are several studies have been found on the shrimp wastewater globally. In the case of Bangladesh, shrimp process wastewater related study is a few. Most of the study in Bangladesh has been determined the characteristics of shrimp process wastewater and determined the impacts of this untreated wastewater nearby. Islam *et al.* (2004) have been shown the BOD_5 value at most 7000 mg/L in Japan. Park *et al.* (2001) reported that in the

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commercial fishing industries of the Island, typical BOD_5 reading measured in the effluent of one seafood processing factory was 1000-5000 mg/L. Waldon (1991) reported that shrimp processing wastewater caused by low DO concentration in Bayou Grand Chaillou. Carawan *et al.* (1986) reported the range of BOD_5 of 200-1000 mg/L, COD of 400-2000 mg/L, TSS of 100-800 mg/L of seafood processing wastewater. These studies have been conducted outside of Bangladesh and the subcontinent. To find appropriate characteristics of wastewater of seafood process industries required study based on the local shrimp processing facilities. Thomas *et al.* (2015) to characterize the physiochemical analysis of seafood industries wastewater in Kerala, India. According to this study, value was varied from 560 mg/L to 1226.6 mg/L, COD from 1666 mg/L to 3666 mg/L, Total Solids were varied from 1203mg/L to 6754 mg/L. However, to provide wastewater treatment facilities in local seafood processing industries required local industry based study. This has been conducted by Billah (2016), and he conducted a wide range of studies in the Khulna region. This study reported DO of 1.7±0.12 mg/L, TDS of 1777±553 mg/L, TSS of 543±187 mg/L, BOD_5 of 377±15 mg/L, and COD of 593±10 mg/L. These all the studies are not most recent. In these circumstances, the study has been conducted in very recent (October 2017 to July 2018) and measured wastewater characteristics of shrimp process wastewater in the Khulna region. However, the studies conducted in Bangladesh did not provide the treatment solution only reported the impacts of it. This study has been provided a tentative treatment solution that is cost-effective and able to meet the national standards of effluent parameters. Worldwide many types of treatment facilities are available. From this number of treatment facilities, a suitable process was needed to select for the shrimp processing industry in the Khulna region of Bangladesh. Barros *et al.* (2009) has expressed a technique for seafood industries wastewater treatment based on high organic loading rate and low organic loading rate which was based on the shrimp processes facilities in Europe. Tay *et al.* (2016) discussed in his research, to accomplish biological treatment aerobic and anaerobic both types of bacteria are engaged. However, in this study, there was no anaerobic facility. Nevertheless, the bench-scale wastewater treatment plant has reduced the mentionable amounts of solids. Some literature reported suspended growth process is best as a biological treatment. In this study, the suspended growth system with an extended aeration process was used. This is because extended aeration will not allow creating anaerobic condition.

2. METHODOLOGY

Wastewater was collected from the selected industry, which located at Bagmara, under the Rupsha Thana, Khulna district of Bangladesh. The samples were collected from the common outlet drain of the factory. The sampling point and factory location is given in Figure 1 and 2. According to the standard sampling method (SESDPROC-306-R2) and selected parameters were measured in the laboratory. Based on the result of raw wastewater, the treatment process was selected, and design calculation was performed on the basis of this result. According to this result, a bench-scale treatment plant was fabricated and installed in the Civil Engineering building of KUET. Wastewater was fed into the designed bench-scale treatment plant. Samples were examined in the environmental engineering laboratory of KUET. The result of the examined was recorded and analyzed by spreadsheet software (MS Excel). Based on the result obtained, the bench-scale treatment plant was analyzed. In the same manner, design calculation was also analyzed. This study has been performed from October 2017 to July 2018. The research methodology of the study is given in the following Figure 3.

From the chosen shrimp processing industry, wastewater was collected and selected parameters like pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were tested. Laboratory test data of raw wastewater characteristics is given in the following Table 1.

An extended aeration activated sludge method was selected as the treatment process. Though the above values were obtained from the laboratory test a range of value was considered as design criteria and it is given in the following Table 2.

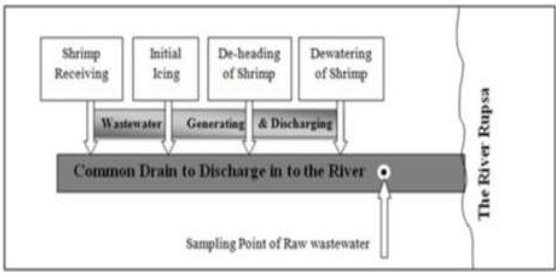

Figure 1: The Sampling Point of Raw Wastewater Collection

Figure 2: The factory Location Map

Table 1: Raw wastewater characteristics

Parameters units should be presented in the second column	Unit	Receiving shrimps and initial washing	Initial icing (or IQF)	Deheading	Dewatering or production room
pH	-	7.5	7.51	7.61	7.66
Dissolved Oxygen	Mg/L	1.39	1.26	1.83	1.46
Biochemical Oxygen Demand	Mg/L	270	234	489	362
Chemical Oxygen Demand	Mg/L	756	655	1370	1013
Total Suspended Solids	Mg/L	640	80	50	480
Total Dissolved Solids	Mg/L	2380	3380	2380	2900

Table 2: Range of design criteria that considered as design value

pH	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	TDS (mg/L)
7 – 9.5	1 – 2	360	450 – 650	300	1500 – 3500

A bench-scale treatment plant was designed based on the above data (Table 2) of different parameters. The process flow diagram is given in the following Figure 4. Twenty milliliters per minute (20ml/min) flow was maintained. Design calculation was performed based on the data given in Table 2. The calculated result of design with design consideration is precisely given in the following Table 3. Primary and secondary clarifier volume and size were kept the same. One aeration unit was used.

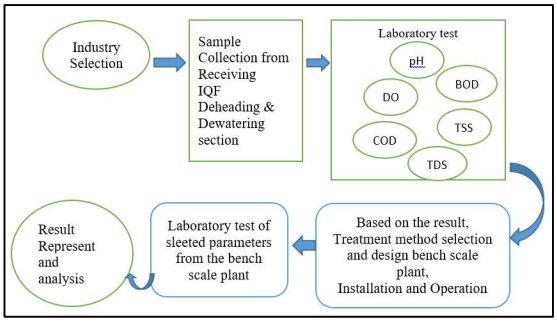

Figure 3: Research Methodology

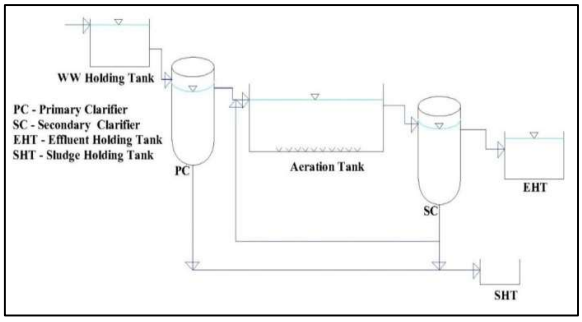

Figure 4: Process Flow Diagram of the Bench-Scale Plant

Table 3: Design consideration and design data of bench-scale WW treatment plant

Primary Clarifier	**Aeration Basin**
Flow (Q), m^3/s – 20 ml/min	
Influent SS – 300 mg/l	Influent SS – 150 mg/l
Influent BOD_5 – 360 mg/l	Influent BOD_5 – 250 mg/l
SS Removal Capacity – 50%	Effluent BOD_5– 30 mg/L
BOD_5Removal Capacity – 30%	Growth Rate Constant, K_s 100 mg/L BOD_5
Hydraulic Retention Time (HRT) – 1.0 hr	Maximum Growth Rate Constant (μ_m)– 2.5/d
	Decay rate (K_d)– 0.05 / d
Volume of clarifier (Process Zone)– 1.3 Liter = 79.33 Cubic Inch	Yield Coefficient for Conversion of BOD_5 into Bacterial Cells (Y) – 0.50 mg MLVSS/mg BOD_5 remv.
Diameter – 0.1 m = 4 inch	Length & Width 0.32 m (12 inch) & 0.18 m (7 inch)
Surface Area – 12.5 $inch^2$	Surface Area – 0.0576 m
Liquid Depth – 0.17 m = 6.5 inch	Liquid Depth – 0.13 m
Tank Type – Circular	Aeration Volume - 3 L/min Continues and Completely mixed Diffused Aeration (by Aquarium stone diffuser)
Composition of Tank –High Density Polyethylene (HDPE)	

The bench-scale biological wastewater treatment plant was installed and operated regularly. Samples were collected from this bench scale plant and examined. Sample collected from the bench-scale plant once in a week. There were 13 to 15 sample collected in this study. The layout and cross-section of the plant and an original photograph of the plant is given in Figures 5 and 6.

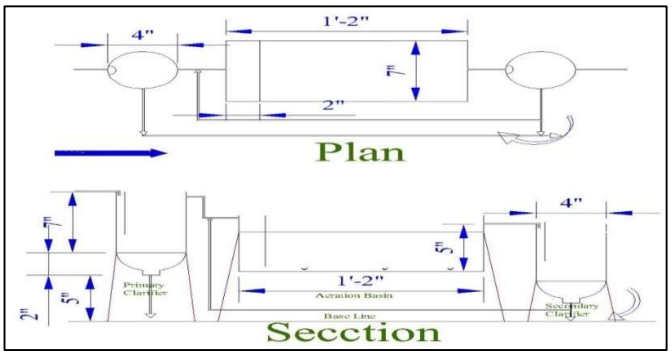

Figure 5: Layout and cross section of designed bench scale WWTP

Figure 6: The bench scale biological wastewater treatment plant

3. RESULT AND DISCUSSION

The bench-scale treatment plant was run continuously. Therefore, it was checked with different parameters regularly. Samples were collected from an equalization basin, primary clarifier, aeration basin, and secondary clarifier of the bench-scale plant. Selected parameters were tested and recorded. Based on the treatment results the performance of the bench-scale plant was analyzed and represented. The following is a detailed discussion of the performance analysis of the bench-scale plant.

3.1 pH & Dissolved Oxygen

The differences in the pH values of raw wastewater and treated wastewater were not found very much in this study. In raw wastewater, pH found typically 7.0 – 8.0. This pH condition is good for process design and bacterial growth. Therefore, no chemical was needed to use. The lowest value of pH was found 7.31 whereas the highest one was 8.53 in raw wastewater. There were thirteen samples of raw wastewater that were measured for pH and the average arithmetic mean value was calculated 8.03 and the standard deviation was found 0.37. Finally, treated wastewater leaves through the secondary clarifier. Due to settling and aeration, pH was reduced in little amount. The variation of pH was state of being 7 to 8. Effluent contained an average pH of 7.73. The Bangladesh standard of pH value is 6 – 9 for effluent discharging into the environment. The average pH value indifferent unit of the bench-scale plant is given in the Figure 7.

Dissolved Oxygen (DO) in raw wastewater of shrimp process wastewater was found low to critically low. The least value of DO of raw wastewater was measured 0.75 mg/L and the highest one was 3.56 mg/L. The arithmetic mean value was determined 2.07 mg/L. According to the Department of Environment (DoE) guideline (known as Bangladesh guideline), the DO value for wastewater (WW) discharging is 4.5 to 8.0 mg/L. The DO value was gradually increased after each unit of operation. In aeration basin air was injected consequently DO increased. After the final clarifier sample was measured and found the DO level above 4.5 mg/L. The higher one was found 6.3 mg/L and the arithmetic average value was noted at 4.68 mg/L. Raw sample characteristics and effluent characteristics after treatment with Bangladesh effluent discharge standards are given in Table 4. The following Figure 8 is presented the average DO value in different unit operations of

the bench-scale plant. Here, the first one is shown DO value of raw wastewater or inlet wastewater of the bench-scale plant. It is shown from the following Figure 8 that the value of DO was gradually increased.

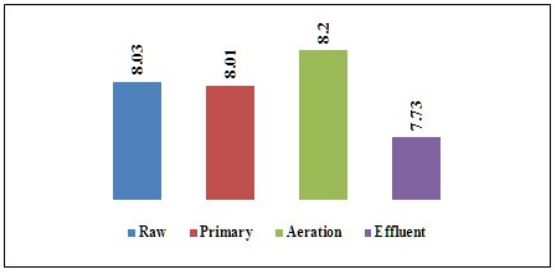

Figure 7: pH value of different unit operation

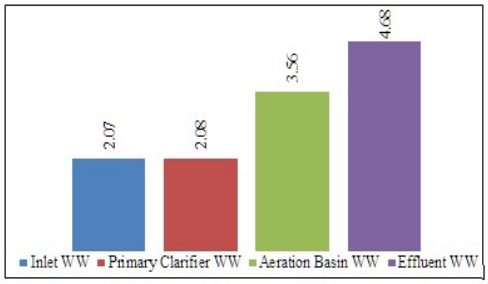

Figure 8: DO value of the different unit operation

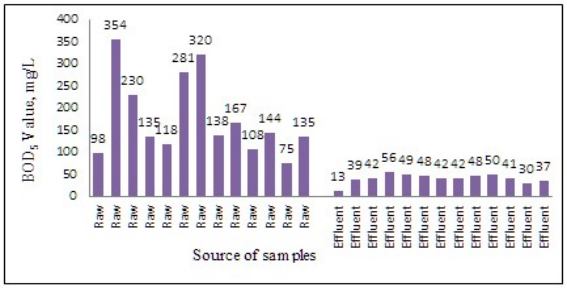

Figure 9: Biochemical Oxygen Demand of raw wastewater and effluent

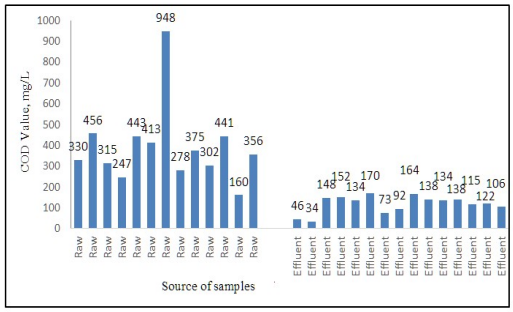

Figure 10: Chemical Oxygen Demand of raw wastewater and effluent

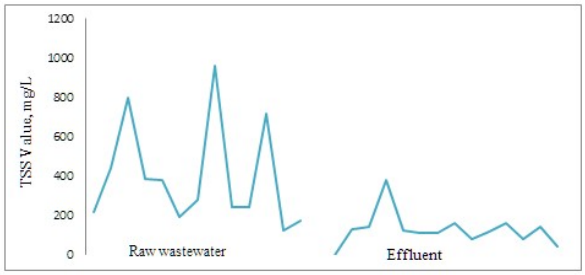

Figure 11: Total suspended solids removal in bench scale plant

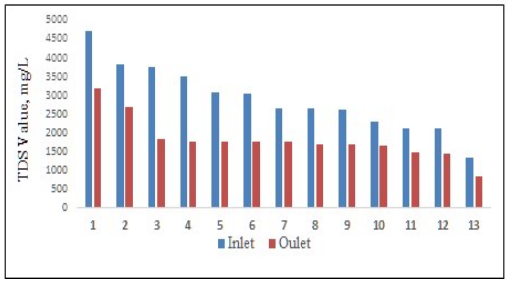

Figure 12: Total Dissolved Solids removal in bench scale plant

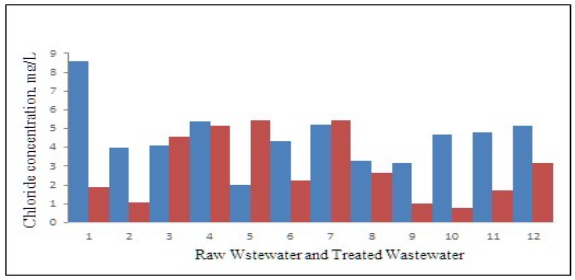

Figure 13: Chloride concentration of Wastewater and Effluent

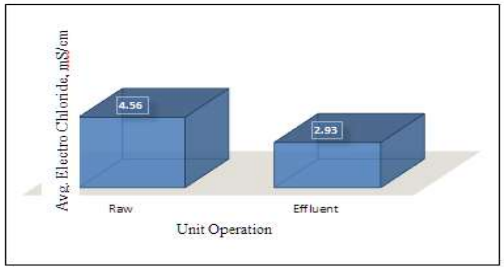

Figure 14: Average EC Value of Raw Wastewater and Effluent of the study

3.2 Biochemical Oxygen Demand

Five-day Biochemical Oxygen Demand of raw wastewater was measured and found an average of 177 mg/L. The higher value was found 354 mg/L and the lower one was 75 mg/L. $BOD_5$was decreased in the primary clarifier, aeration basin and finally secondary clarifier. The primary clarifier was removed 5.64% of BOD_5. In aeration basin normally steady variation was found and performance was flat rate to removal. Aeration basin was removed almost 50% of BOD_5. All values of BOD_5 in secondary clarifiers were measured and found below

50 mg/L. The average value of BOD_5 of effluent was noted 41.3 mg/L. This value meets the maximum permissible value of ECR 1997 of the Bangladesh Government. The average reduction rate was calculated of 77%. The state of the removal of BOD_5 of the bench-scale wastewater treatment plant (WWTP) is given in the following figure 9. The first half bars are shown about the BOD_5 value of raw wastewater that varied from 75 to 354 mg/L and the treated wastewater value is shown in the second half bars that varied from 13 to 56 mg/L.

3.3 Chemical Oxygen Demand

The typical value of the COD of this study was found 160 to 948 mg/L. The arithmetic mean value was calculated 355 mg/L for the same raw wastewater. Between these ranges (160-148 mg/L) most of the values were recorded above 200 mg/L. In aeration basin significantly removed COD from wastewater. Almost half of the COD value was reduced in the aeration basin. In the final stage, the secondary clarifier has taken the final action and reduced COD significantly. The higher value was found 170 mg/L and the lower one was 34 mg/L of effluent. Arithmetic mean value was found 117 mg/L whereas the national standard is 200 mg/L. There were 15 samples were tested of effluent. The average rate of COD removal was found 67% of the bench-scale plant. The level of COD in raw wastewater and treated effluent through the bench-scale treatment plant is given in Figure 10.

3.4 Total Suspended Solids

Total Suspended Solids (TSS) was found 383 mg/L averagely of 13 samples. The highest value of TSS of raw wastewater was found at 960 mg/L and the lowest one was 127 mg/L. The Bangladesh standard of TSS value is 150 mg/L and raw wastewater contained more than 150 mg/L of TSS. Shrimp process wastewater contains a huge number of organic solids. Raw wastewater was given fluctuated value of TSS. This was because all samples were not collected at the same time and date. Samples were collected and measured in the environmental engineering laboratory. Effluent was contained less than the standard level (50 mg/L) when the wastewater leaving from the bench-scale plant. The designed bench-scale plant reduced the mentionable level of TSS. There were 13 samples of treated effluent were taken under test. The higher one of the COD values of treated effluent was found 380 mg/L and the lower one was 43 mg/L. The arithmetic mean value was noted 137 mg/L. All samples from the bench-scale plant were found under 150 mg/L. The following Figure 11 is giving a clear concept about the TSS of raw and effluent wastewater.

3.5 Total Dissolved Solids

Dissolved solids or Total Dissolved Solids (DS or TDS) represent all organic and inorganic constituents present in wastewater in dissolved form. TDS also represents the total salt of water. This study was found a large amount of TDS in wastewater of the selected shrimp processing industry. It was recorded up to 4720 mg/L dissolved solids in raw wastewater. On the other hand, the least value was recorded 1325 mg/L. The Bangladesh standard for TDS is 2100 mg/L to discharging wastewater in the environment. The designed bench-scale plant significantly separated total dissolved solids from the wastewater in both primary and secondary clarifiers. Thus, the final effluents contain mentionable fewer amounts of TDS rather than raw wastewater. Final effluents were measured and found the mean value of TDS 1805 mg/L. There were thirteen samples measured and noted all samples found under the standard level of TDS of effluent. The following Figure 12 is represented the TDS value of raw samples and effluent after treatment.

3.6 Chloride

This study was measured and found effluents concentration more or less 1000 mg/l of chloride. The national guideline of wastewater discharge by Bangladesh Government has referred chloride of 600 mg/L. A higher one was found 1475 mg/L and the lower one was only 275 mg/L of untreated wastewater. After the treatment through the designed bench-scale plant effluent wastewater contain chloride averagely 292 mg/L. It was not that all value maintained the below level of standard. One sample among six samples was found 650 mg/L. Except this one all samples were found under the standard level. The following Figure 13 is shown the result measured from the laboratory test. The blue color is representing the chloride concentration of raw wastewater whereas the brown color is representing the chloride concentration in the treated effluent.

3.7 Electrical Conductivity

This study was found a maximum of 8.57 mS/cm which is 8577 µS/cm of electrical conductivity. The arithmetic mean value was recorded at 4.56 mS/cm. That means the sample was contained moderate-higher of TDS or Salt concentration. The minimum value was found at 2 mS/cm. The output wastewater contain EC is almost half of the inlet wastewater. The arithmetic mean of EC of treated sample was found 2.93 mS/cm. The higher one was

noted 5.46 mS/cm and lower one 0.8 mS/cm. The value of EC of raw wastewater and effluent is given in the following Figure 14.

The overall performance of the designed bench-scale plant for removal was calculated 77% and COD removal efficiency was calculated 67%. Dissolved oxygen was increased double than raw sample contain. Calculated effluent DO was increased 126% of influent DO. For dissolved solids removal, the bench-scale plant was performed 37% reduced of its raw value. Suspended solids removal rate was measured 64%, thus the plant was treated shrimp processed wastewater excellently. The following Table 4 is expressing the increasing or decreasing level of different parameters of the bench-scale plant. Also, Table 4 is given a comparative figure of raw wastewater characteristics with treated wastewater characteristics of the study.

Table 4: The increasing and decreasing rate of different parameters of the bench-scale plant

Parameter(s)	Bangladesh Standard for Discharging	Raw Wastewater (Avg.) of the Bench-scale	Effluent Wastewater (Avg.) of the Bench-scale	Decrease %	Increase %	Unit
pH	6-9	8.03	7.73	3.73		
DO	4.5-8	2.07	4.68		126.08	mg/L
BOD_5	50	177	41	76.83		mg/L
COD	200	355	117	67.04		mg/L
TDS	2100	2,894	1,805	37.62		mg/L
SS	150	383	137	64.22		mg/L

When designed the plant, it was considered influent BOD_5 contain 360 mg/L whenever in raw wastewater contained average BOD_5 177 mg/L which kept 30 to 50 mg/L after treatment. To get the value below 50 mg/L BOD_5 in treatment effluent, the plant had removed 70% of BOD_5. In design consideration; it was assumed 30% of BOD_5 will remove after primary clarification. However, the designed bench-scale plant removed only 6% of BOD_5. Rest 60 to 65% of BOD_5 was removed in the aeration basin and final clarifier. Aeration basin removed 50% of BOD_5 raw wastewater and the final clarifier removed 77% BOD_5 of raw wastewater.

4. CONCLUSIONS

It was the first study about wastewater treatment of shrimp processing industries in Khulna using local treatment setup so far. It is clear from the study; no chemical coagulation was required; this was because microorganisms played a major role in the elimination of solids from wastewater. The treatment efficiency was moderate in practical when continuous treatment will be run with a large amount of wastewater the efficiency of treatment will be increased. The design criteria of this study can be considered for biological wastewater treatment plant design of a typical seafood processing industry. Based on the obtained data and result it can be said that the wastewater of the shrimp processing industry is mid-level wastewater. Because its waste parameters value was neither high nor very low. The design criteria that set for the study have shown without chemical coagulation and plain sedimentation can remove solids effectively.

pH value was not found in mentionable change. Effluent BOD_5 was found averagely 41 mg/L and the removal rate of the bench-scale treatment plant was measured 77%. On the other hand, the effluent was contained the COD value of 117 mg/L average and the reduction rate of COD was found 67%. DO level was improved in effluent 2.07 to 4.68 mg/L. The suspended solids removal percentage was measured 62% and thus final effluent was contained 137 mg/L. On the other side, dissolved solids were deducted 37% and hence effluent was contained 1805 mg/L on average. Chloride removal was calculated 64% and 292 mg/L in the effluent. Therefore, the bench-scale plant was performed moderately in treatment.

This study has been found the initial characteristics of shrimp processed wastewater. The study has also been found that no industry set up effluent treatment plant in their factory and direct discharge wastewater into the River Rupsa. The owners of the factory think wastewater purification is too expensive and they do not take any treatment because there is no government pressure. This study shown the biological wastewater treatment will be cost-effective for the shrimp process wastewater and the design criteria used in the study can remove waste and meet the national standard for effluent discharging significantly.

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