

Performance Evaluation of Anaerobic-Aerobic Treatment for the Wastewater of Potato Processing Industry: A Case Study of a Local Chips Factory

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Abstract

A study was conducted to assess the performance of anaerobic-aerobic treatment system of a local potato processing industry. The wastewater treatment plant (WWTP) consisted of primary treatment, upflow anaerobic sludge blanket (UASB), activated sludge process (ASP) and secondary clarifier. The study analyzed the physical, chemical and biochemical parameters of the influent (raw sewage) as well as the effluent from each component of the plant. Grab wastewater samples were collected on weekly basis and analyzed for the pH, settleable solids (SS), total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). Study revealed that mean influent wastewater concentrations of TSS, TDS, SS, BOD and COD were 840 mg/L, 2,396 mg/L and 18.7 mL/L, 2,186 mg/L and 3,679 mg/L, respectively. The mean percentage removal efficiency in UASB for TSS, BOD and COD was found to be 56%, 61 % and 51%, respectively. The mean percentage removal efficiency in activated sludge system for TSS, BOD and COD was found to be 70%, 57% and 48%, respectively. The mean percentage removal efficiency of combined anaerobic-aerobic system for TSS, BOD and COD was found to be 93%, 90% and 80%, respectively. The mean effluent concentrations of TSS, BOD and COD were 52 mg/L, 197 mg/L and 784 mg/L, respectively. The effluent from WWTP satisfied NEQS for TSS (200 mg/L) while NEQS for BOD (80 mg/L) and COD (150 mg/L) were not satisfied. Some operational problems, responsible for inadequate efficiencies of the plant components, were identified and solutions were suggested for these problems.

Key Words: *Industrial wastewater; anaerobic-aerobic treatment; potato processing; UASB; activated sludge*

1. Introduction

Surface water bodies in developing countries are under serious threat as a result of untreated discharge of effluents from industrial, agricultural, and domestic activities (Kambole, 2003). Pakistan being not an exception, water pollution is the most serious environmental issue due to disposal of liquid waste in surface waters. Among them the most significant are domestic wastewater and industrial effluents.

Food processing industry being the second largest industrial sector in Pakistan (GOP, 2004) is

among the major polluters of the water bodies. Food handling, processing, packaging and storing leads to an inherent generation of wastewater (Carawan et al, 1979). Large volumes of high strength carbohydrate rich wastewaters (Steven et al, 2005) are produced which are characterized by high biochemical oxygen demand (BOD), chemical oxygen demand (COD), large amounts of total suspended solids (TSS) and various inorganic constituents (Smith, 1976). In addition, the effluents also contain high loads of cleansing, blanching agents, salts and fibers (UNEP, 2004).

Complete treatment of the highly polluted wastewaters emerging from the food processing industry is, thus, vital to conserve water bodies from contamination. It may be noted that even a single food industry i.e. potato processing plant can create a waste load equivalent to a city of 200,000 people (Hung, 1983) which if discharged untreated; may totally disrupt the ecology of the receiving water body.

In Pakistan, wastewater treatment is still at an infancy stage. Most of the industries have yet to install a wastewater treatment facility. Under these circumstances, studies of the existing local industrial wastewater treatment systems may help in establishing and optimizing the future industrial wastewater treatment facilities. In this context a wastewater treatment plant (WWTP) of a potato processing industry in Lahore was selected for study. The objectives of this study were: (1) to evaluate of the efficiency of the individual units of WWTP and also the overall efficiency of the anaerobic-aerobic treatment system for potato chips processing industry; (2) to study various problems faced; both during the commissioning and operational phase of WWTP along with their most likely causes and measures taken to troubleshoot these problems.

2. MATERIALS AND METHODS

2.1 Wastewater Treatment Plant Description

The objective of the WWTP, of the said potato processing industry, was to bring the wastewater

quality characteristics within the National Environmental Quality Standards (NEQS) for liquid industrial effluents. The WWTP consisted of primary settling tank (PST), upflow anaerobic sludge blanket (UASB) reactor and activated sludge system installed in the order stated above. Fig.1 presents a schematic of the WWTP and the location of sampling points of wastewater for evaluating the efficiency of wastewater treatment plant.

Table 1. Presents the design hydraulic capacity and the design influent and effluent wastewater characteristics, for the WWTP. The final effluent concentrations determined during this study were compared with those given in Table 1.

2.2 Wastewater Sampling

For the sake of evaluating the efficiency of WWTP and its individual components, grab samples were collected on weekly basis from four points (Fig.1). The sampling point along with its brief description is given in Table 2. Each sampling point was sampled 15 times. Since it was not possible to take composite samples, therefore, sufficient grab samples were collected to arrive at an average performance value for the plant.

2.3 Analytical Procedures

Table 3 depicts the various parameters analyzed for wastewater samples collected.

For sampling point 1, BOD and COD were measured twice for the same sample; first time for the

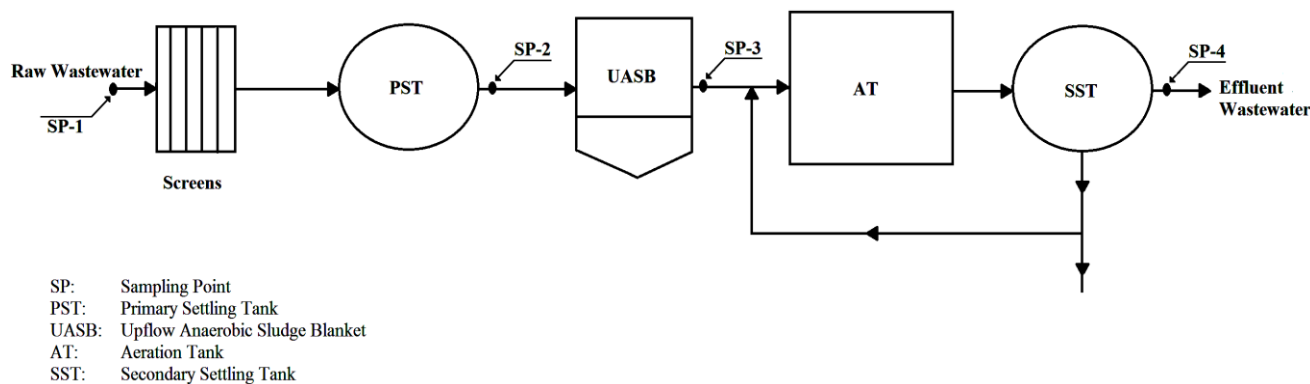


Fig.1 Schematics of wastewater treatment and sampling points at the potato processing plant (Hayee, 2008)

Table 1: WWTP design parameters (Hayee, 2008)

Parameter	Value
Design hydraulic capacity	
Design Daily Wastewater Flow	680 (m ³ /d)
Design Peak Hour Wastewater Flow	30 (m ³ /h)
Design influent wastewater characteristics	
Biochemical Oxygen Demands (BOD)	5,654 (mg/L)
Chemical Oxygen Demand (COD)	11,305 (mg/L)
Total Suspended Solids (TSS)	7,533 (mg/L)
Total Kjeldahl Nitrogen (TKN)	296 (mg/L)
Design effluent wastewater characteristics (per NEQS)	
pH Value	6 – 9
Biochemical Oxygen Demands (BOD)	80 (mg/L)
Chemical Oxygen Demand (COD)	150 (mg/L)
Total Suspended Solids (TSS)	200 (mg/L)

Table 2: Description of sampling points

Sampling Point (SP)	Description
SP-1	Influent chamber of screens
SP-2	Effluent channel of primary sedimentation tank
SP-3	Effluent channel of UASB
SP-4	Effluent channel of secondary settling tank

Table 3: Sampling points and parameters measured

Sampling Point	Parameters
1	pH, TS ¹ , TDS ² , TSS ³ , BOD, COD, BOD (filtered), COD (filtered), SS ⁴
2	pH, , TSS, BOD, COD
3	pH, TSS, BOD, COD
4	pH, TSS, BOD, COD

Total Solids¹; Total dissolved solids²; Total suspended solids³; Settleable Solids⁴

raw sample and second time for the filtered sample*. Whatman GF/C filter with pore size 1.2 µm was used for filtering wastewater. . The results for filtered sample actually show the dissolved portion of BOD and COD in the raw potato processing wastewater. Laboratory of Institute of Environmental Engineering and Research (IEER) at UET Lahore and Laboratory of Environmental Sciences (LES), Ferozepur Road Lahore were used for testing these collected samples. Test procedures, as laid down in the Standard Methods for the Examination of water and wastewater (1998), were used and are shown in Table 4. Performance of the WWTP was monitored through

* BOD of raw wastewater is referred as Total BOD and BOD after filtration is referred as filtered BOD.

weekly measurement of parameters mentioned in Table 3.

Table 4: Testing procedures used (Standard Methods, 1998)

Sr. No.	Test	Test Procedure
2.	pH	4500–H ⁺ B
3.	Total Solids (TS)	2540 B
4.	Total Suspended Solids (TSS)	2540 B
5.	Total Dissolved Solids (TDS)	2540 C
18.	Five Day Biochemical Oxygen Demand (BOD)	5210 B
20.	Chemical Oxygen Demand (COD)	5220 B
22.	Phosphorus (P)	4500 – PC
23.	Nitrogen (N)	4500–N _{org} B

3. RESULTS AND DISCUSSION

3.1 Characterization of Raw Potato Wastewater

Combined wastewater from different potato processing streams was received in screen chamber i.e. the sampling point 1. Test results of parameters from sampling point 1 gave the characteristics of raw potato processing wastewater. Furthermore, BOD (filtered) and COD (filtered) were also measured. The detailed results are exhibited in Table 5.

The pH of the raw wastewater measured during the study period varied between 4.9 to 6.7. For most of the time (about 60 % of the total readings) pH, however, remained between 6.0 and 6.7. Most of the research on potato processing wastewater shows that it is acidic in nature (Burk, 1998; Lehto et al., 2005; Barampouti, 2005; Kobya et al., 2006; Ma et al. 2007).

Total suspended solids of the raw wastewater varied between 409 and 1,964 mg/L during the whole study period. For about 70 % of the total readings, influent TSS concentrations remained less than 850 mg/L while for the remaining readings TSS concentrations ranged from 1,150 to 1,964 mg/L. Significant portion of suspended solids comes from washing of raw potatoes which contributes high amounts of suspended and fixed solids in water (Pailthorp et al, 2007). The reported TSS values in potato processing wastewater lie in a range of 500 to 10,000 mg/L (Burk, 1998; Barampouti, 2005; Ma et al. 2007; Pailthorp et al., 2007; Kalyuzhnyi et al., 1998; Dornbush, et al., 1992; Mishra, 2004). Total dissolved solids of the raw wastewater varied between 1,068 and 4,424 mg/L during the study period with a mean value of 2,396 mg/L. For about 75 % of the total readings, influent TDS concentrations remained less than 2,600 mg/L while

Table 5: Test results of parameter for Sampling Point 1 (Raw wastewater characteristics)

Sr. No	Sampling Date	pH	TSS	TDS	TS	SS	BOD	BOD	COD	COD
			mg/L	mg/L	mg/L	mL/L	(Total) mg/L	(Filtered) Mg/L	(Total) mg/L	(Filtered) mg/L
1	27-Feb-2008	6.42	459	2247	2708	10.2	1260	1027	2040	1680
2	7-Mar-2008	6.15	1964	3108	5078	20	3180	1027	4480	1280
3	17-Mar-2008	5.52	1576	2218	3792	15	3180	1590	3360	1840
4	26-Mar-2008	6.7	832	2368	3204	4.5	1135	815	1920	1400
5	2-Apr-2008	6.01	1796	3328	5028	10	1725	1240	2560	2000
6	21-Apr-2008	6.34	432	2220	2654	4.5	1560	900	2080	1360
7	30-Apr-2008	5.05	1192	2044	3238	30	5100	2460	5440	2600
8	8-May-2008	6.16	478	2552	3032	1.5	3600	2160	6700	4900
9	22-May-2008	6.08	588	2308	2900	20	1800	150	2000	400
10	5-Jun-2008	6.24	560	2198	2760	25	1860	750	4000	2700
11	12-Jun-2008	6.13	490	2576	3070	30	1800	1440	4600	3900
12	25-Jun-2008	4.92	830	4424	5256	25	960	1020	2200	1300
13	2-Jul-2008	5.6	409	2200	2610	30	1920	1320	4900	3900
14	16-Jul-2008	5.21	511	1068	1582	25	1800	1320	5300	4700
15	11-Aug-2008	5.93	490	1080	1570	30	1920	1320	3600	3400
	Mean	5.90	840.47	2395.93	3232.13	18.71	2186.67	1235.93	3678.67	2490.67
	Range	4.92 – 6.7	409 - 1964	1068 – 4424	1570- 5256	1.5 - 30	960 - 5100	150- 2460	1920-6700	400-4900
	SD ¹	0.52	532.29	816.59	1131.49	10.33	1109.41	559.32	1526.97	1378.01
	CV ²	8.88	63.33	34.08	35.01	55.20	50.74	45.26	41.51	55.33

¹Standard Deviation; ² Coefficient of Variation

for the remaining readings TDS concentrations ranged between 3,100 and 4,425 mg/L.

Total solids (TS) varied between 1,570-5,256 mg/L during the study period with their mean value of 3,232 mg/L. For about 75 % of the total readings, influent TS concentrations remained less than 3,800 mg/L while for the remaining readings TS concentrations ranged from 5,000 and 5,256 mg/L. Settleable solids varied between 1.50 and 30 mL/L during the study period with their mean value of 18.7 mL/L. For most of the time (about 60 % of total readings), influent SS concentrations remained above 20 mL/L.

The measured raw influent wastewater BOD varied between 960 and 5,100 mg/L during the study period with its mean value of 2,186 mg/L. For about 70 % of the total readings, influent raw wastewater BOD concentrations ranged between 1,500 and 3,600 mg/L. The major contributor of BOD in potato processing waste is the peeling process. Peter (1972) concluded that approximately up to 90 % of the BOD in effluent wastewater is generated from the peeling operations of potato processing industry. The work of previous research workers show that BOD of potato processing wastewater lie in a range of 700-6000 mg/L (Barampouti, 2005; Pailthorp et al., 2007; Mishra, 2004; Dornbush, et al., 1992; Kobya et al., 2006; Syed et al., 2005)

COD varied between 1,920 and 6,700 mg/L during the whole study period with a mean value of 3,679 mg/L. For about 85 % of the total readings, the influent raw wastewater COD concentrations ranged between 2,000 and 5,500 mg/L. Work carried out by others shows that COD lie in range of 550 to 21,000 mg/L (Dornbush, et al., 1992; Kalyuzhnyi, 1998; Barampouti, 2005; Mishra, 2004; Syed et al., 2005; Ginkel et al, 2005; Kobya et al., 2006; Blonskaja, 2006; Katarino et al, 2006; Ma, 2007;).

The measured mean BOD and COD values for raw wastewater give a BOD/COD ratio of 0.59 designating a major portion of the influent wastewater COD to be of biodegradable nature. This finding is in line with the result of Sayed et al. (2005) who also determined the raw potato processing wastewater BOD/COD ratio to be 0.57. Nora et al (1999) and Kobya et al (2006) however determined

the values of raw BOD/COD for potato processing wastewater to be 0.75.

Filtered BOD, which actually shows the readily biodegradable dissolved portion of the organic matter, varied in a range of 150 to 2460 mg/L with an average value of 1235 mg/L. If we compare the filtered BOD with the total BOD, we come to the conclusion that on average, 56% of the total BOD was in a dissolved form, which is quite a substantial portion. Filtered COD values ranged from 400 to 4900 mg/L, with a mean value of 2490 mg/L. Comparison between the mean values of raw and filtered COD shows that filtered COD is about 65 % of the raw COD on average. Hence a significant portion of total COD is in soluble form.

3.2 BOD/COD Ratio

The BOD/COD values for raw samples varied from 0.34 to 0.95 with a mean value of 0.61. This shows that considerable portion of organic matter (about 61 % on average) is biodegradable in nature. Experimental data of BOD and COD for raw wastewater is plotted and correlated as shown in Fig 2. The equation of the linear regression line fitted to the plotted data may be used to express the correlation between BOD and COD as shown by equation-1;

$$\text{BOD} = 0.485 \text{ COD} + 401.8 \quad (1)$$

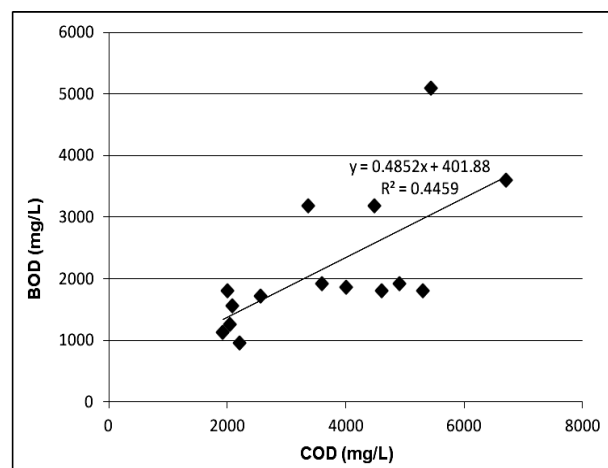


Fig.2 Correlation between BOD and COD for raw wastewater

Correlation coefficient (R^2) has a value of 0.445 which shows a moderate positive correlation between the plotted parameters.

3.3 Performance Evaluation of WWTP

Grab wastewater samples taken from the screen chamber (SP-1), effluent channel of primary sedimentation tank (SP-2), effluent channel of UASB (SP-3) and effluent channel of SST (SP-4) were tested on weekly basis to establish the performance of the following:

- 1) Primary settling tank
- 2) UASB
- 3) Activated sludge process
- 4) Overall performance of combined anaerobic-aerobic treatment system

Parameters used for the performance evaluation were TSS, BOD and COD

3.3.1 Performance Evaluation of Primary Settling Tank (PST)

Wastewater samples from the screen chamber (SP-1) and the effluent channel of PST (SP-2) were used to determine the operational performance of PST. Mean percentage removal efficiency for TSS, BOD and COD has been shown in Fig. 3. The error bars show the minimum and maximum percentage removal efficiency during the study period, for a specific parameter.

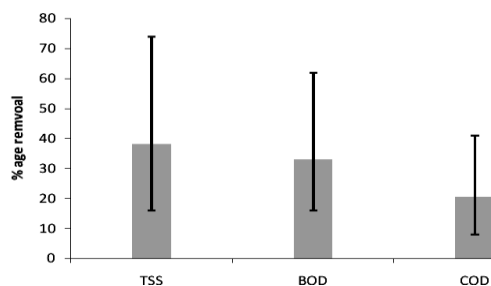


Fig.3 Mean percentage removal for TSS, BOD and COD in PST.

TSS concentrations at SP-2 (effluent channel of PST) varied from 322 mg/L to 948 mg/L with a mean value of 452.6 mg/L during the study period. The data is highly variable with its standard deviation of 195.5 mg/L and coefficient of variation of 43.2 %. The removal efficiency for TSS varied greatly from 18 to 70 % with a mean value of about 38 %. The mean percentage removal at PST is in line with the reported values i.e., 30 to 60 % (Steel and McGhee, 1991).

BOD concentrations at SP-2 (effluent channel of PST) as determined from the research results varied from 367 mg/L to 2580 mg/L with a mean value of 1443 mg/L. Removal efficiency for BOD in PST varied from 16 – 62 % with mean removal of about 33 %. BOD removal in PST is somewhat lower than reported in literature, which is about 40-60% for potato wastewater (Pailthorpe et al, 2007).

COD concentrations at SP-2 (effluent channel of PST) varied from 1350 mg/L to 5,848 mg/L with a mean value of 2913 mg/L. Removal of COD in PST was not much significant. It varied from 13 – 34 % with mean removal of only about 20 %.

3.3.2 Performance Evaluation of UASB

Wastewater samples collected from the effluent channel of PST (SP-2) and the effluent channel of UASB (SP-3) were used to determine the operational performance of UASB during the study period. Parameters used were TSS, BOD and COD. Their percentage removal has been shown in Fig. 4 with vertical error bars exhibiting the maximum and minimum percentage removals during the study period.

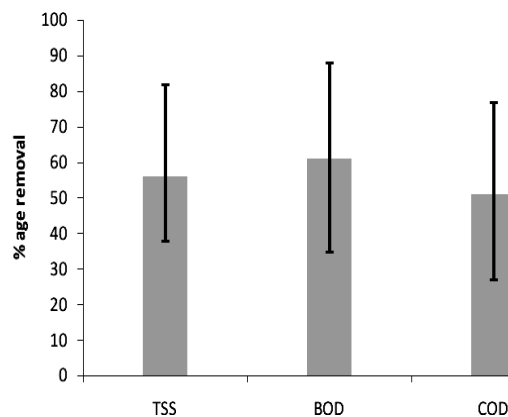


Fig.4 Mean percentage removal of TSS, BOD and COD in UASB

TSS concentration at SP-3 (effluent channel of UASB) varied from 74 mg/L to 400 mg/L with a mean value of 191 mg/L during the study period. Significant variations in the TSS removal efficiencies of UASB were also observed during the study period. The percentage removal efficiency in UASB varied from 38 to 82%, with a mean value of 56 %.

BOD concentration at SP-3 (effluent channel of UASB) varied from 180 mg/L to 1432 mg/L with its mean value of 546 mg/L during the study period. BOD removal efficiencies of the UASB varied from 38 % to 88 % with a mean removal of about 61 % during the study period. COD concentration at SP-3 (effluent channel of UASB) varied from 400 mg/L to 2480 mg/L with a mean value of 1,401 mg/L during the study period. COD removal efficiencies of the UASB varied from 27 % to 77 % during the study period. The mean percentage removal efficiency for COD was found to be 51%. According to literature, COD removal efficiencies ranging between 63-90 % can be obtained for potato processing wastewater by means of UASB (Kalyuzhnyi et al., 1998; 4. Lepisto & Rintala, 1999). As anaerobic processes are sensitive to pH, great variation in removal efficiency for COD were observed at UASB due to changing pH in the influent to UASB. The lower efficiency is attributed to decreased pH for some period of time.

3.3.3 Performance Evaluation of ASP

Activated sludge system included both aeration tank (AT) and the secondary settling tank (SST). Wastewater samples were collected from the UASB effluent (SP-3) and the effluent channel of secondary Settling Tank (SP-4). These samples were analyzed to assess the operational performance of activated sludge system with respect to TSS, BOD and COD. The mean percentage removal of these parameters has been shown in Fig. 5. Vertical error bars are used to show the maximum and minimum values of percentage removals during the study period.

TSS concentrations at SP-4 (effluent channel of SST) varied from 4 mg/L to 128 mg/L with their mean concentration of 52 mg/L during the study period. Most of the samples collected from the UASB effluent and SST effluent indicated the TSS removal efficiency of the activated sludge system to be higher than 70 % with a maximum TSS removal efficiency of 97 %. The mean percentage removal efficiency for TSS was found to be 70 %.

BOD concentrations at SP-4 (effluent channel of SST) varied from 12 mg/L to 780 mg/L with its mean value of 193 mg/L during the study period. The effluent BOD data of SST was very inconsistent with

its standard deviation of 198.5 mg/L and coefficient of variation of 102 % indicating a variable performance of the activated sludge system. The mean percentage removal efficiency of ASP for BOD was found to be about 57%. The large variations and poor performance of ASP for BOD removal is attributed to no standby arrangement of power during electricity breakdown.

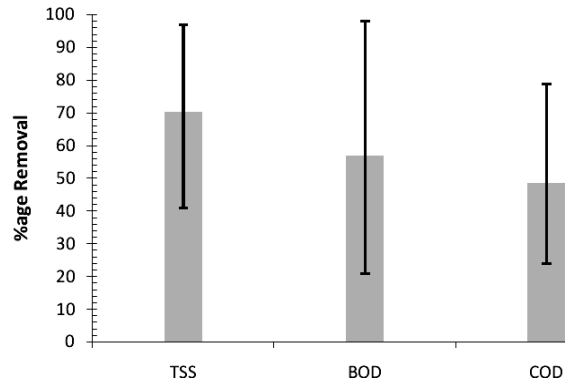


Fig.5 Mean percentage Removal of TSS, BOD and COD in ASP

COD concentrations in SP-4 (effluent channel of ASP) varied from 200 mg/L to 1,865 mg/L with a mean value of 784 mg/L during the study period. The SST effluent data is very inconsistent with its standard deviation of 606 mg/L and coefficient of variation of 77 % indicating a variable performance of the activated sludge system for COD removal. Removal efficiency varied greatly from 24 to 79 % with the mean percentage removal of about 49 %.

3.3.4 Overall Performance of Combined Anaerobic-Aerobic Wastewater Treatment System

Wastewater samples collected from the screen chamber (SP-1) and the effluent channel of secondary settling tank (SP-4) were used to assess the overall operational performance of the combined anaerobic-aerobic system. The mean values of removal efficiency for TSS, BOD and COD are shown in Fig. 6. The vertical error bars show the minimum and maximum value of percentage removals.

The overall removal efficiencies exhibited by the combined anaerobic-aerobic system are discussed below:

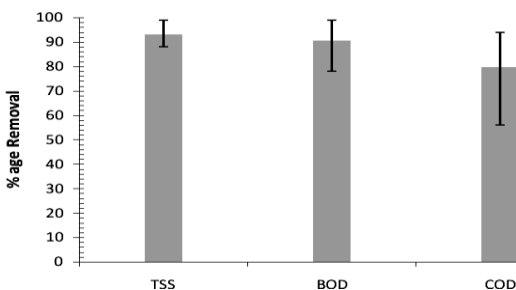


Fig. 6: Mean percentage removal of combined anaerobic-aerobic treatment system

- Overall TSS removal efficiency of the combined system was observed to range between 88-99% with a mean value of 93%. The mean effluent concentration of TSS was 52 mg/L which meets the NEQS limits of 200 mg/L.
- Overall BOD removal efficiency of the combined anaerobic-aerobic system ranged between 78 - 99 % with maximum removal efficiencies obtained during the initial study period. The removal efficiencies exhibited by the combined system are in line with the findings of Hadjivassilis et al (1997) who reported 99.5 % BOD removal efficiencies while adopting UASB followed by activated sludge treatment for a potato chips wastewater. Effluent BOD concentration of as low as 30 mg/L was even obtained during the study period. Such a lower concentration of effluent BOD indicates WWTP to be fully capable of effectively handling the incoming organic pollution loads under proper operational control. However, the mean BOD of the finally treated effluent was 192 mg/L and it is above the limits prescribed by NEQS i.e. 80 mg/L.
- Overall COD removal efficiency of the combined anaerobic-aerobic system ranged between 56 - 94% with maximum removal efficiencies

obtained during the initial study period with effluent COD up to 200 mg/L. Combined anaerobic-aerobic system have been reported to furnish maximum COD removal efficiencies ranging between 96.2-99.2 % for potato processing wastewaters (Hadjivassilis et al, 1997; Dornbush et al., 1972). The maximum COD removal efficiency determined for the combined anaerobic aerobic system under study is, however, somewhat lower than these reported efficiencies. The mean percentage removal efficiency of combined anaerobic-aerobic system for COD was found to be 79.9% with an effluent concentration of 784 mg/L which is much higher than the limits prescribed by NEQS i.e. 150 mg/L. When the mean effluent COD concentration of the finally treated effluent is compared with mean BOD, it appears that a large portion of the organic load is non-biodegradable.

Mean concentrations of wastewater at different treatment stages and comparison of effluent characteristics with NEQS are shown in Table 6.

4.3 Statistical Analysis of Performance Data

There were several data sets for each unit operation (PST, UASB, ASP) for the removal of major pollutants (TSS, BOD, COD). Average percentage removal of major pollutants in each operational unit has been report in the above section. Average percentage removal show differences in the performance of different unit operation. Are these differences statistically significant? This can be evaluated by an analysis of variance. The summary of performance results for each unit operation is shown in Table 7. It appears from this table that ASP has better performance with respect to TSS, while UASB is performing better with respect to the removal of BOD and COD.

Table 6: Mean characteristics of wastewater at different treatment stages and overall efficiency of WWTP

Parameter	Screening chamber (SP-1)	PST Effluent (SP-2)	UASB reactor Effluent (SP-3)	SST Effluent (SP-4)	NEQS values	Mean percentage removal efficiency of combined anaerobic-aerobic treatment system (%)
pH	5.9	4.76	6.43	7.56	6 – 9	–
TSS (mg/L)	840	737	357	59	200	92
BOD (mg/L)	2187	2309	749	228	80	80
COD (mg/L)	3679	4564	1658	986	150	78

Table 7: Mean percentage removal of major pollutants in each unit operations

Sr. No.	Unit Operation	Pollutant and mean percentage removal		
		TSS	BOD	COD
1	PST	37.9	33	20
2	UASB	56.4	61	51
3	ASP	70	56	48

Anova (Analysis of Variance) was used to establish the statistical significance of results shown in Table 7. The null hypothesis used for Anova was that all the units operations are performing in a similar manner. Whether Anova supports this null hypothesis, has been check at an α level of 0.05

3.4.1 Anova analysis for TSS removal

SUMMARY

Groups	Count	Sum	Average	Variance
PST	15	569	37.93	390.20
UASB	15	846	56.4	234.68
ASP	15	1056	70.4	244.11

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	7955.511	2	3977.75	13.73	2.58E-05	3.21
Within Groups	12166.13	42	289.66			
Total	20121.64	44				

It can be seen that F value is 0.00002, which is much less than α value of 0.05 and F value is more than F_{crit} . Thus null hypothesis is wrong and the performance indicated by mean value is also statistically significant. Thus ASP performance for TSS removal is better than other unit operations.

3.4.2 Anova results for BOD removal

SUMMARY

Groups	Count	Sum	Average	Variance
PST	15	494	32.93	207.07
UASB	15	914	60.93	247.92
ASP	15	855	57	992.71

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6893.378	2	3446.689	7.14	0.002138	3.220
Within Groups	20267.87	42	482.5683			
Total	27161.24	44				

For BOD, the P value is less than 0.05 and F value is more than F_{crit} , therefore showing that null hypothesis is wrong. UASB is performing better for BOD removal from the rest of the two unit operations.

3.4.3 Anova results for COD removal

SUMMARY

Groups	Count	Sum	Average	Variance
PST	15	307	20.47	111.55
UASB	15	759	50.6	284.97
ASP	15	729	48.6	439.97

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8517.51	2	4258.75	15.27	1.04E-05	3.22
Within Groups	11710.93	42	278.83			
Total	20228.44	44				

Anova for COD also shows that null hypothesis is wrong. P value is less than 0.05 and F value is more than F_{crit} clearly showing that the better performance of UASB observed from mean values, also has statistical significance.

On the basis of Anova, it can be confirmed that UASB is performing better than other two units for BOD and COD removal, while ASP has better performance for TSS removal. Performance of ASP for BOD removal needs improvement while PST should perform best for TSS, but it is not. Interventions are needed to improve the TSS removal performance of PST.

4. Conclusions

1. The mean removal efficiencies of the anaerobic-aerobic treatment system for TSS, BOD and COD are 92%, 90% and 78% respectively.
2. Mean effluent concentrations for finally treated wastewater for TSS, BOD and COD were 52, 192 and 784 mg/L, respectively. Thus TSS was within NEQS (200 mg/L) while BOD (80 mg/L) and COD (150 mg/L) were exceeding NEQS.
3. The poor performance of UASB was due to the fluctuations in pH, when pH remained lower than 4.2 its performance drastically reduced.
4. The poor performance of activated sludge process for BOD and COD is mainly attributed to the consistent power failures with no provision of oxygen to the microbes during that period.
5. The overall performance efficiency of the plant is not satisfactory.

Various problems encountered during the commissioning and operation of WWTP were: (1) silt accumulation in various compartments receiving raw wastewater; (2) excessive foaming in activated sludge system; (3) occasional rising of sludge at the surface of secondary settling tank; and (4) severe sludge bulking in activated sludge system. Measures taken to control these problems were;

- Separation of raw potato washing stream from the potato processing plant and provision of a silt chamber for this stream solved silt accumulation problem.
- Use of antifoam effectively reduced foaming in aeration tank.
- Increased sludge recycling rates minimized rising of sludge in SST.
- Regulated flows and raised dissolved oxygen levels in aeration tank diminished sludge bulking.

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