Enhanced Removal of Organics From Primary Settling Tank of An Activated Sludge Process Using Thickened And Aerobically Digested Sludges As Flocculent

Dr. A.B. Gupta, Dr. R.K. Vyas, and D.R. Jangid

Abstract—This paper describes the effect of addition of different secondary sludges of two sewage treatment plants (STPs), with raw sewage of STP Delawas, Jaipur based on conventional activated sludge process (ASP) as flocculent in order to achieve enhanced removal of both suspended and soluble organic matter in the primary settling tank (PST). Excess sludge from secondary clarifier from Delawas plant after thickening was utilized for the purpose of settling experiments followed by similar sequence for secondary and aerobically digested sludges from STP Brahmapuri, Jaipur (based on extended aeration ASP with provision of aerobic sludge digesters) in controlled proportions. The concentrations of BOD, fBOD, COD and TSS were monitored after 30 min to 120 min of settling and the impact of this modified process on energy balance was assessed. It was observed that the addition of these sludges resulted in enhanced removal of organics especially in the first hour of settling compared to the settling of raw sewage in the PST. The maximum removals of up to 84 %, 41%, 31 % and 7% respectively for TSS, COD, BOD5 and filtered BOD5 was obtained for 2-hour settling with 10 mL of aerobically digested sludge mixed with 1000 mL of raw sewage compared to the corresponding values of 39, 49, 43 and 22% respectively for the mass balance calculations of the existing scenario of raw sewage settling superimposed with the return sludge of the same volume being fed to the aeration tank. The results indicate that this process modification may help increase the organic content of the primary sludge due to the removal of much finer suspensions and hence the energy generation potential. An equivalent benefit would be obtained due to lesser amount of organics passing on to the aeration tank thereby requiring reduced aeration for biological oxidation. Above all, the sludge being biological in nature would have no adverse impact on long term use in the reactor offering a sustainable solution.

Index Terms---Sewage Treatment, PST, Sludge As Flocculent

I. INTRODUCTION

Primary settling tanks (PSTs) are the units where settleable solids in wastewater are separated under gravity resulting in about 50-70% of TSS are removal (Metcalf and Eddy, 2006). Removal of TSS is affected by settling characteristics of particles of different sizes (Tebbutt and Christoulas, 1975). It is reported that performance of PSTs can be enhanced by the addition of chemicals such as ferric chloride, alum, polymers etc (Heinke et al., 1980), but such chemicals may interfere with the subsequent biological process and hence not preferred as a sustainable solution.

Waste activated sludge recirculation to the PST was applied to enhance the TSS removal efficiency by Haung and Li, (2000), Haung and Li, (2000) who reported that this application significantly improved the efficiency of PST and secondary treatment. In our recent study (Jangid et al., 2014, 2015), batch experiments with the addition of secondary excess sludge in 10-50 mL volumes to 1000 mL of the raw sewage of STP Delawas, Jaipur were carried out. The 30 mL addition yielded the maximum benefit resulting in removal of TSS, BOD and fBOD of 65.3, 44.3, 46.4 and 23.5% respectively compared to the corresponding removal of 41.1, 47.7, 41.3 and 22.4% respectively for the existing scenario of the plant. Though the removal of TSS was enhanced significantly, the difference in other parameters was not significant. The results of the study led to further experiments on enhancement of performance of PST through the addition of thickened sludge from the same plant as well as sludges from secondary settling tank as well as aerobic digester of a nearby STP of Jaipur working on the principles of extended ASP. This paper presents results of the aforementioned study designed to assess the effect of conditioning of sludge through aeration for performance enhancement.

II. EXPERIMENTAL

Controlled sludge addition in different volumes to the raw sewage was carried out in 1200 mL capacity reactors representing PST. These were made of glass having conical bottom with a cylindrical top as shown in Fig 1.

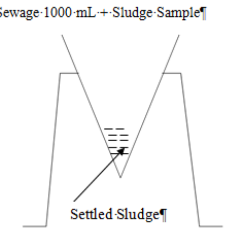

Fig. 1. Experimental Set Up (Inhoff Cone).

Grab samples of sewage were used in study and were drawn as per the guidelines specified in manual on Water and Wastewater analysis issued by CPHEEO, Ministry of Urban Development, New Delhi (1993). Samples of raw sewage of 20 L were collected from the inlet of the STP in plastic bottles and analyzed for the parameters, TSS, COD, BOD and filtered BOD as per the procedures laid down in above CPHEEO guidelines. Initially 1000 mL of raw sewage sample was filled in the Imhoff cone and subjected to settling analysis. Settled samples were drawn from the top surface of the glass cone at regular intervals of 30 min for 2 h. The experimental set up was kept in the air-conditioned laboratory, where the temperature was maintained at about 27°C. All the samples were analyzed for TSS, COD, total BOD, and filtered BOD.

Hot air oven was used for the measurement of TSS at 105^{o} C. BOD_5 was measured at 20^{o} C with Winkler's Azide modified method. COD was analysed using open reflux method; and for filtered BOD_5, 0.45 micron Millipore filter

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paper was used. All above tests were conducted at the Laboratory situated in STP premises. For analysing the samples of different sludges for BOD analysis, a known volume of these was first acidified with H_2SO4 in order to solubilise the solids and then it was neutralized with NaOH before being put in the BOD bottle for analysis.

Thickened excess secondary sludge was drawn from STP Delawas and 10 mL, 20 mL 30 mL, 40 mL and 50 mL of it were added to 1000 mL of raw sewage in different sets of Imhoff cones for settling analysis. After addition of controlled volume of sludge in the raw sewage, the mixture was shaken simply by turning the covered vessel up and down three to four times and a sample was drawn to represent time zero. The mixture was then allowed to settle and after time intervals of every 30 min for the next 2 h, samples were drawn from the clear top surface and analyzed for BOD_5, COD, TSS and filtered BOD_5 concentrations. Each test was duplicated in a parallel set up. The measurements from these parallel experiments were utilized in estimating the average values. The settling experiments were also repeated several times with samples of raw wastewater under the same conditions to obtain the baseline settling data. The sludge samples used were also analyzed for same parameters as described for the settled sewage samples for carrying out mass balance. The mass balance of parametric values was carried out for the two scenarios- first, representing the existing flow scheme (Fig 2) for the observed values; and second set up representing modified flow scheme (Fig 3) for calculations based on settled raw sewage parameters and sludge characteristics.

Similar experiments were conducted with the return sludge as well as the aerobically digested sludge obtained from STP Bhramapuri, which is a 27 MLD STP based on extended aeration ASP. All these sludge samples were mixed with 1000 mL of raw sewage of STP Delawas in different proportions and subjected to settling experiments in the manner described above.

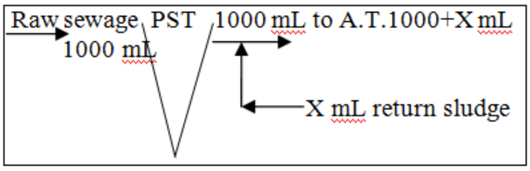

Fig. 2: Existing Flow Scheme

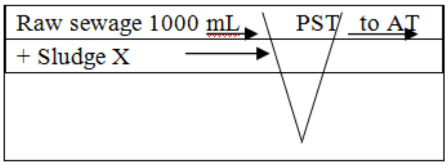

Fig. 3: Modified Flow Scheme

Similar experiments were conducted with the return sludge as well as the aerobically digested sludge obtained from STP Bhramapuri, which is a 27 MLD STP based on extended aeration ASP. All these sludge samples were mixed with 1000 mL of raw sewage of STP Delawas in different proportions and subjected to settling experiments in the manner described above

III. Results And Discussion

Experiments With Addition Of Thickened Secondary Excess Sludge From STP Delawas

Experiments were conducted with the addition of thickened sludge in 10, 20, 30, 40 and 50 mL volumes in 1000 mL of raw sewage of STP Delawas. The settling characteristics of raw sewage and the properties of return sludge are presented in Tables 1 and 2.

TABLE I
RESULTS OF SETTLING OF RAW SEWAGE SAMPLE I

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5 mg/L	Filtered BOD_5 removal, %
0	576	0	768	0	300	0	89	0
30	245	57%	402	48%	185	38%	81	9%
60	226	61%	380	51%	172	43%	75	16%
90	218	62%	367	52%	167	44%	71	20%
120	201	65%	348	55%	164	45%	67	25%

TABLE II
CHARACTERISTICS OF RAW SEWAGE AND THICKENED EXCESS SLUDGE OF STP DELAWAS

Parameters	Thickened Sludge Of STP Delawas
TSS, Mg/L	28756
COD, Mg/L	7226
BOD_5 , Mg/L	825
Filtered BOD, Mg/L	142

The results obtained with the addition of 10 mL,20 mL, 30 mL, 40 mL and 50 mL thickened return sludge are shown in Table -3 for 90 min and 2 h settling periods only. The results of the complete experiment are described in details in the subsequent section.

TABLE III
OBSERVED AND CALCULATED VALUES WITH ADDITION OF THICKENED EXCESS SLUDGE IN VARIOUS VOLUMES

Parameters mg/L	Observed values for		Observed value	Calculated values for	Observed value	Calculated values for
	Only Raw sewage	Raw sewage + sludge (Immediate after addition)	After 90 min	Raw sewage + sludge (assumed to be arriving at aeration tank.	After 120 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.
With 10 mL Sludge						
TSS	576.0	855.0	268.0	500.6	219.0	483.7
COD	768.0	831.0	385.0	434.9	356.0	416.1
BOD5	300.0	305.2	170.0	173.5	168.0	169.5
fBOD5	89.0	89.0	69.0	71.7	68.0	67.7
With 20 mL Sludge						
TSS	576.0	1128.5	276.0	777.6	232.0	760.9
COD	768.0	894.6	392.0	501.5	372.0	482.9
BOD5	300.0	310.3	174.0	179.9	172.0	177.0
fBOD	89.0	90.0	72.0	72.4	69.0	68.5
With 30 mL Sludge						
TSS	576.0	1396.8	279.0	1049.2	250.0	1032.7
COD	768.0	956.1	402.0	566.8	376.0	548.3
BOD5	300.0	315.3	178.0	186.2	187.0	183.3
fBOD	89.0	90.5	75.0	73.1	70.0	73.1
With 40 mL Sludge						
TSS	576.0	1659.8	283.0	1315.6	252.0	1299.3
COD	768.0	1016.4	388.0	630.8	428.0	612.5
BOD	300.0	320.2	196.0	192.3	201.0	189.4
fBOD	89.0	91.0	78.0	73.7	73.0	69.9
With 50 mL Sludge						
TSS	576.0	1917.9	286.0	1577.0	254.0	1560.8
COD	768.0	1075.5	392.0	693.6	452.0	675.5
BOD	300.0	325.0	216.0	198.3	210.0	195.5
fBOD	89.0	91.5	81.0	74.4	86.0	70.6

It was observed that the percentage removal after first 1 h of settling for TSS, COD, BOD and filtered BOD were in the range of 63-81-%, 50-59%, 35-39 % and 2-16 % respectively. The corresponding calculated removals in these parameters were in the range of 17-41 %, 3,4-44%, 35-42 % and 14-16% respectively. The maximum TSS removal was observed with 50 mL sludge addition for 2 h settling period showing the effect of flocculation obtained through the addition of secondary excess sludge. The observed TSS removals were much higher than their corresponding values calculated for the existing scenario confirming the benefits in terms of removal of much finer suspensions in the modified scheme. The maximum COD removal was observed as 61% with 50 mL sludge addition at 2 h settling period, which was also much higher than the calculated maximum value of 50% for 2 h settling with 10 mL sludge thereby showing significant additional benefit due to the modified process. The maximum BOD and fBOD removals were 45% and 24% respectively, which were for the case of 10 mL sludge addition at 2 h settling. These values were comparable to the calculated values for the simulated existing scenario. Among the above experiments, the observed values for 10 mL sludge addition were most favorable for the removal of TSS and COD.

Experiments With Addition Of Secondary Excess Sludge From STP Brahmapuri

Since the return excess sludge from STP Delawas was not in a good physiological condition due to excessive return flows, it was decided to bring the return excess sludge from STP Brahmapuri, which works on the principles of extended aeration ASP. Experiments were conducted with the addition of this sludge in 10, 20, 30, 40 and 50 mL volumes in 1000 mL of raw sewage of STP Delawas. The settling characteristics of raw sewage and the properties of return sludge are presented in Table 4.

TABLE IV: RESULTS OF SETTLING OF RAW SEWAGE II

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5, mg/L	Filtered BOD_5 removal, %
0	510	0	654	0	293	0	82	0
30	236	54%	390	40%	184	37%	80	2%
60	216	58%	371	43%	170	42%	76	7%
90	209	59%	357	45%	166	43%	73	11%
120	198	61%	338	48%	164	44%	65	21%

TABLE V
CHARACTERISTIC OF RETURN SLUDGE OF 27 MLD
(EXTENDED AERATION PROCESS)

Parameters	Return sludge of 27 MLD STP Brahampuri (extended aeration)
TSS, mg/L	24936
COD, mg/L	3104
BOD_5, mg/L	590
Filtered BOD_5, mg/L	145

The results obtained with the addition of 10-50 mL return sludge are shown in Table -6 for 90 min and 2 h settling periods only. The results of the complete experiments are detailed in the subsequent section.

TABLE VI
ADDITION OF RETURN SLUDGE (27 MLD- EXTENDED AERATION PROCESS) IN VARIOUS VOLUMES

Parameters	Observed values for Only Raw sewage	Observed values for Raw sewage + sludge (Immediate after addition)	Observed value After 90 min	Calculated values for Raw sewage + sludge (assumed to be arriving at aeration tank.	Observed value After 120 min	Calculated values for Raw sewage+ sludge (assumed to be arriving at aeration tank.
With 10 mL Sludge						
TSS (mg/lit)	510.0	751.8	248.0	212.8	198.0	197.5
COD (mg/lit.)	654.0	678.3	365.0	384.2	330.0	365.4
BOD_5 (mg/lit.)	293.0	295.9	164.0	170.2	165.0	168.2
Filtered BOD_5	82.0	82.6	65.0	73.7	62.0	65.8
With 20 mL Sludge						
TSS (mg/lit)	510.0	988.9	246.0	693.8	242.0	683.1
COD (mg/lit.)	654.0	702.0	406.0	410.9	404.0	392.2
BOD_5 (mg/lit.)	293.0	298.8	192.0	174.3	190.0	172.4
Filtered BOD	82.0	83.2	74.0	74.4	69.1	66.6
With 30 mL Sludge						
TSS (mg/lit)	510.0	1221.4	256.0	929.2	207.0	918.5
COD (mg/lit.)	654.0	725.4	385.0	437.0	341.0	418.6
BOD_5 (mg/lit.)	293.0	301.7	174.0	178.3	172.0	176.4
Filtered BOD	82.0	83.8	72.0	75.1	67.0	67.3
With 40 mL Sludge						
TSS (mg/lit)	510.0	1449.5	260.0	1160.0	211.0	1149.5
COD (mg/lit.)	654.0	748.2	394.0	462.7	348.0	444.4
BOD_5 (mg/lit.)	293.0	304.4	182.0	182.3	178.0	180.4
Filtered BOD	82.0	84.4	72.0	75.8	69.0	68.1
With 50 mL Sludge						
TSS (mg/lit)	510.0	1673	264	1386.5	216	1376.0
COD (mg/lit.)	654.0	771	402	487.8	352	469.7
BOD_5 (mg/lit.)	293.0	307	188	186.2	182	184.3
Filtered BOD	82.0	85	74	76.4	71	68.8

The observed removal of TSS, COD, BOD5 and filtered BOD5 in first hour was 63 %, 37%, 30 % and 7% respectively indicating that first hour is more important in the removal of TSS, COD and BOD5. In the second hour the additional removal in TSS, COD, BOD5 and filtered BOD5 observed were 9%, 10%, 14% and 18 % respectively. It indicated that the second hour was more effective in the removal of BOD and filtered BOD (soluble fraction) probably due to the absorption into the cells. The maximum removal in TSS and COD of 87 and 54 % was observed with the addition of 50 mL after 2 h settling. Maximum removals of 44 and 25 % in BOD & fBOD were observed with addition of 10 mL after 2 h settling. The calculated values of removal in TSS, COD, BOD and fBOD were 41% with 10 mL sludge, 41% with 30 mL of sludge, 43 and 20% with 10 mL of sludge addition respectively. Thus, the observed values were highly favorable in terms of removal of TSS and COD, while marginal benefits were obtained for BOD & filtered BOD removals. Addition of 10 mL of this sludge provided optimum results

Settling Experiments With Aerobically Digested Sludge From STP Brahmapuri

STP Brahmapuri is the only plant in India that has a provision of aerobic digestion of sludge. Settling experiments were conducted with 10, 20, 30, 40, and 50 mL of this sludge added to 1000 mL of raw sewage from STP Delawas. The settling characteristics of raw sewage sample II and the properties of aerobically digested sludge are represented in Tables 7 and Table 8. The results obtained with the addition of 10-50 mL of aerobically digested sludge are shown in Table 7 for 90 min and 2 h settling periods only. The results of the complete set of experiments are detailed in the subsequent section.

TABLE VII

RESULTS OF SETTLING OF RAW SEWAGE SAMPLE III

Duration, min	TSS, mg/L	TSS removal, %	COD, mg/L	COD removal, %	BOD_5, mg/L	BOD_5 removal, %	Filtered BOD_5, mg/L	Filtered BOD_5 removal, %
0	514	0	692	0	287	0	82	0
30	236	54%	396	43%	181	37%	78	5%
60	214	58%	372	46%	167	42%	75	9%
90	207	60%	354	49%	163	43%	72	12%
120	201	61%	338	51%	162	44%	64	22%

TABLE VIII

CHARACTERISTIC OF AEROBICALLY DIGESTED SLUDGE OF 27 MLD STP BRAHAMPURI (EXTENDED AERATION PROCESS)

Parameters	Aerobically digested sludge of 27 MLD STP Brahampuri
TSS, mg/L	29900
COD, mg/L	3200
BOD_5, mg/L	535
Filtered BOD, mg/L	130

TABLE IX

ADDITION OF AEROBICALLY DIGESTED SLUDGE (27 MLD- EXTENDED AERATION PROCESS) IN VARIOUS VOLUMES

Parameters	Observed values for		Observed value	Calculated values for	Observed value	Calculated values for
	Only Raw sewage	Raw sewage + sludge (Immediate after addition)	After 90 min	Raw sewage + sludge (assumed to be arriving at aeration tank.	After 120 min	Raw sewage+ sludge (assumed to be arriving at aeration tank.
With 10 mL Sludge						
TSS (mg/lit)	514	805.0	251.0	210.2	195.0	495.0
COD (mg/lit.)	692	716.8	371.0	382.2	330.0	366.3
BOD_5 (mg/lit.)	287	289.5	165.0	166.7	153.0	165.7
Filtered BOD_5	82	82.5	62.0	72.6	58.0	64.7
With 20 mL Sludge						
TSS (mg/lit)	514	1090.2	260.0	789.2	240.0	783.3
COD (mg/lit.)	692	741.2	381.0	409.8	356.0	394.1
BOD_5 (mg/lit.)	287	291.9	197.0	170.3	167.0	169.3
Filtered BOD	82	82.9	72.0	73.1	61.0	65.3
With 30 mL Sludge						
TSS (mg/lit)	514	1369.9	249.0	1071.8	244.0	1066.0
COD (mg/lit.)	692	765.0	432.0	436.9	413.0	421.4
BOD_5 (mg/lit.)	287	294.2	198.0	173.8	191.0	172.9
Filtered BOD	82	83.4	74.0	73.7	68.0	65.9
With 40 mL Sludge						
TSS (mg/lit)	514	1644	252	1349.0	249	1343.3
COD (mg/lit.)	692	788	436	463.5	416	448.1
BOD_5 (mg/lit.)	287	297	201	177.3	196	176.3
Filtered BOD	82	84	76	74.2	71	66.5
With 50 mL Sludge						
TSS (mg/lit)	514	1913	260	1621.0	252	1615.2
COD (mg/lit.)	692	811	438	489.5	418	474.3
BOD_5 (mg/lit.)	287	299	204	180.7	198	179.8
Filtered BOD	82	84	77	74.8	72	67.1

It was observed that the removal of TSS, COD, BOD5 and filtered BOD5 in first hour was 84 %, 41%, 31 % and 7% respectively establishing that first hour settling is more important in the removal of TSS, COD and BOD5. In the second hour the additional removal in TSS, COD, BOD5 and filtered BOD5 observed were 3%, 13%, 16% and 23 % respectively indicating that the second hour was especially more effective in the removal of filtered BOD (soluble fraction) due to the absorption into the cells, which are high in concentration. The maximum removal in TSS of 87% was observed with the addition of 50 mL sludge after 2 h settling and maximum removal of COD was 54 % with 10 mL sludge after 2 h settling. Maximum removals of 47 and 30 % in BOD & f BOD were observed with addition of 10 mL after 2 h settling. The calculated values of removal in TSS, COD, BOD and fBOD were 39%, 49 %, 43 and 22% with 10 mL of sludge addition. Thus, the observed values were significantly better than the corresponding values of the calculated parameters simulating the existing scenario. The results of this set of observations were the best with the addition of 10 mL of this sludge. These were the best results out of all the previous experiments, which yielded a clue that the conditioning of the excess thickened sludge through aeration may prove to be very useful as aerobically digested sludge would normally not be available in STPs. Thus, a brief aeration period was given to the thickened sludge of STP Delawas for carrying out another set of settling experiments, the results of which are not shown here.

IV. CONCLUSION

There was a vast improvement in the process that took place after addition of sludges with the best results being obtained after 2 h settling with aerobically digested return sludge. With the modified flow scheme for sludge, we were able to achieve much higher removal of organics in terms of TSS and BOD5 from PST. Power generation units have primary sludges as the major contributor of energy in the digestion process and hence any enhanced removal in PST can increase the energy generation potential greatly and simultaneously any extra removal of organics from PST can result in lesser energy consumption in aeration process as less oxygen demand is reaching the aeration unit. Conditioning of sludge through aeration improved the removals significantly indicating the potential of using this process for field applications.

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