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# Enhancement of Performance of ASP for Organics Removal using Return Sludge as Flocculent in Primary Settling Tank

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***Abstract: Renewable energy production and environmental crisis are the recent issues prevailing in the society. Economic growth of the country depends largely on the availability of the renewable energy. Wastewater treatment systems are huge consumers of electricity for accomplishing the task of the safe and healthy environment. Wastewater systems account for about 1- 5 % of total electricity consumption in a country. It is stated that energy consumption contribution per person is about average values of 12-15 kWh/ person-year considering 80% of water @ 180 L per capita per day is contributing to sewage reaching to STP for treatment and BOD of 50g/d. Hence, there is an urgent demand for reducing this consumption for the overall development of our country.***

***Among the aerobic processes, activated sludge process (ASP) represents the most widespread technology for wastewater treatment in India. In ASP major part of the energy consumption (about 60%) occurs in the aeration tank to provide the proper environment for the treatment of wastewater. In wastewater treatment plants, it is very difficult to make power savings in general because the process is continuous, and, on the other hand, the treatment technology is based on processes (physical, chemical and especially biological) that cannot be switched off or disconnected from the main supplies. The other option is only to modify the processes in order to save energy.***

***A case study for performance analysis of conventional Activated Sludge Process with use of excess sludge as a flocculent in the Primary Settling Tank was carried out to enhance the operational efficiency of secondary treatment unit and improve the settling characteristics in the Primary settling tank. The performance was assessed by setting up a laboratory scale ASP setup and commissioning the reactor at suitable HRT of 6h scaling down it from 12h.***

***The study aims at improving the settling property of primary settling tank thereby reducing the organic load in aeration tank and reducing the energy consumption of the treatment plant.***

***Many encouraging results were observed which supported the concept that efficiency of primary settling tank can be increased by the addition of a suitable quantity of activated sludge. It was observed that compared to the conventional control (all recycled biomass going to AT), the improvement in organics removal in our modified system was 38% at 30+40% recycle combination. This can result in overall reduction of the maintenance cost of STP plants in our country.***

***Keywords: Biological Oxygen Demand, Activated Sludge Process, Chemical Oxygen Demand, Return Activated Sludge, Biomass, and Sludge.***

***Acronyms: Activated Sludge Process (ASP), Aeration Tank (AT), Primary Settling Tank (PST), Return activated sludge (RAS), Biological oxygen demand(BOD), Sewage Treatment Plant (STP), Chemical Oxygen Demand(COD), Mixed Liquor suspended solids (MLSS), Sludge Volume Index (SVI), Dissolved oxygen (DO), Hydraulic Retention Time(HRT), Standard Deviation (SD).***

 

# 1 INTRODUCTION

Environmental protection and energy crisis are two most prominent challenges to the world. It is well recognized that alternative sources of energy are urgently required. Current reliance on fossil fuels is unsustainable due to pollution and finite supplies. While much research is being conducted on a wide range of energy solutions, it does not appear that any one solution alone will be able to replace fossil fuels in its entirety. As such it is likely that a number of different alternatives will be required, providing energy for a specific task in specialized ways in various situations. Wastewater treatment systems are huge consumers of electricity for accomplishing the task of the safe and healthy environment. Wastewater systems account for about 1- 5 % of total electricity consumption in a country. It is stated that energy consumption contribution per person is about average values of 12-15 kWh/ person-year considering 80% of water @ 180 L per capita per day is contributing to sewage reaching to STP for treatment and BOD of 50g/d [Arceivala et al., 2006].

The Activated Sludge Process used for waste water treatment comprises primary treatment unit which includes inlet arrangements, coarse screens, pumps, fine screens and grit separators wherein inorganic impurities are removed. These primary units are generally common in all processes. Further, after flow measurement unit, primary settling tanks are considered for removal of suspended solids and suspended BOD using gravity phenomenon. Generally, about 30-40% suspended solids and 25-35% BOD can be removed in PST. It has been demonstrated earlier that only 25-30% of the organic matter in municipal wastewater is truly soluble and its removal depends on biological oxidation and assimilation processes; whereas the majority of organic matter present in the suspended form can be removed by solid-liquid separation using physical and chemical means [Odengard et al., 2000]. The secondary treatment unit, also called the heart of the ASP process, consists of the aeration tank and the secondary settling tank wherein the bulk of the biological treatment is provided, employing microbes/bacteria for the process. The main function of the aeration tank is to maintain a dense population of microbes. This mixture is called MLSS (Mixed Liquor Suspended Solids). The mixed liquor is passed on to the clarifier tank, where the microbes are made to settle at the bottom. The settled microbes are recycled back to the aeration tank, to have a long retention period within the system. The settling characteristics of suspended particles mainly depend upon the nature of the particles and their concentration in the wastewater [Tebbutt et al., 1975].The secondary clarifiers allow settling of biomass solids in the Mixed Liquor (biomass slurry) coming out of the aeration tank, to the bottom of the clarifier, to thicken the settled biomass, in order to produce a thick underflow, to produce clear supernatant which can be discharged. The clarifier is only a passive device wherein, all the actions occur under gravity. The thick biomass is re-circulated back to the aeration tank. The sludge so collected from the two clarifiers requires proper handling and the use of anaerobic digestion for this sludge treatment has proved to be beneficial in terms of electricity generation through the production of biogas. The potential of using biogas as an energy source has now been widely recognized and current techniques are being developed to upgrade its quality and to enhance energy yield [Güelfo et al., 2011].

Among the aerobic processes, ASP represents the most widespread technology for wastewater treatment in India. In ASP major part of the energy consumption occurs in the aeration tank to provide the proper environment for the treatment of wastewater. The performance of activated sludge process may be enhanced either by a higher sludge concentration or a prolonged retention time in the aeration tank and the performance of the traditional activated sludge process can only be enhanced by the extension of the contact time [Bretscher et al., 2005].

In wastewater treatment plants, it is very difficult to make power savings in general because the process is continuous, and, on the other hand, the treatment technology is based on processes (physical, chemical and especially biological) that cannot be switched off or disconnected from the main supplies. The other option is only to modify the processes in order to save energy. A study at design stage provides an improvement in efficiency of primary clarifier to get more sludge from primary settling tank for anaerobic digestion to produce more biogas to get more power which will overall reduce the power requirement from the grid [Dharmraj Jangid et al., 2014].

Primary sludge is the main source for power generation through anaerobic digestion in any ASP as it contains much higher organic content than the secondary sludge. Thus an efficient PST would lead to additional power generation and consequently lesser BOD load going to the AT. The addition of chemicals in primary settling tanks will create flocs which will result in better sedimentation. The performance of existing settling units will thus become better in terms of reduction in organic load [Heinke et al., 1980]. Use of inorganic coagulants may interfere with the biological process in the AT and hence the process improvement was attempted by using the flocculation characteristics of secondary sludge by putting it in to the PST rather than to the AT as is practiced conventionally.

 

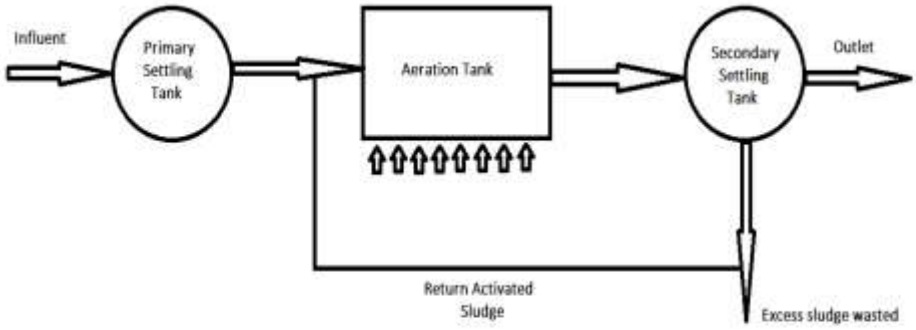


**Figure 1 1: Schematic Diagram of Conventional ASP**

The study aims at improving the settling property of primary settling tank thereby reducing the organic load in aeration tank and reducing the energy consumption of the treatment plant. It was studied that regardless of surface loading on the settling tank, attachment of smaller non settleable particles onto larger ones of separable size is essential to attain high removal efficiency of suspended solids [Svarovsky, L., 2000]. In an effectively operated primary treatment system, SS removal efficiency was typically found in the range as high as 40 to 60%, while that for $BOD_5$, it was between 30-35%. The primary treatment cannot achieve higher levels of $BOD_5$ removal because the majority of the organics in sewage is present either in soluble or finely divided particulate form which is not settleable [Tillman et al., 1991]. The RAS (biomass) in ASP contains extra cellular polymers that have a good flocculation property.

Hence if this activated sludge is recycled in the primary settling tank instead of the aeration tank, it is expected that the settling properties will be enhanced in PST and significantly organic load will be reduced in the aeration tank. This can result in energy savings in the aeration tank due to reduced organic load. In a study, it was analysed that the primary effluent suspended solids concentration has a major influence on the total weight of excess sludge produced in an activated sludge system. Primary effluent suspended solids can be controlled by the addition of organic flocculants to the raw wastewater stream. The resulting flocculation also removes a greater portion of the biochemical oxygen demand than is normally removed across the primary clarifiers. The additional removals of suspended solids and biochemical oxygen demand both reduce excess sludge production. Savings in plant operating costs can result from a reduction of aeration air requirements, a decrease in chlorine demand, and improved filter-ability of the sludge. Final effluent quality also gets improved [Voshel et al., 1968]. It was also studied that it is possible to re-circulate some portion of the waste activated sludge to inlet of the primary sedimentation tanks. The addition of waste activated sludge to raw sewage may improve primary settling efficiency depending on waste excess sludge characteristic [Yetis et al., 2002].

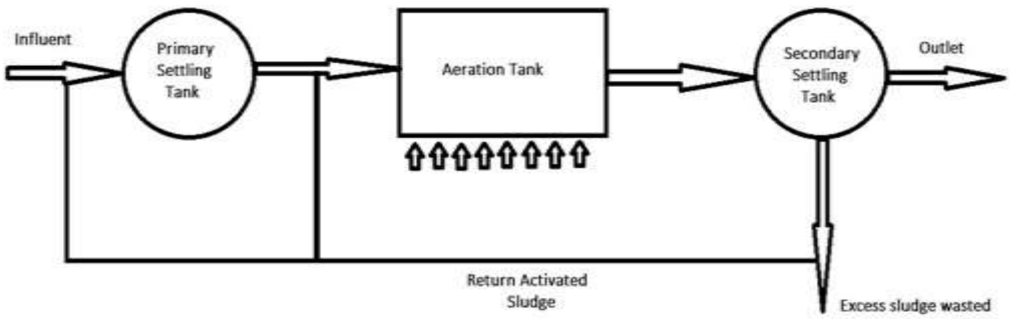


**Figure 1.2: Schematic Diagram of Modifications in Conventional ASP Process**

The major energy fraction of biological sludge from STPs comes from the primary sludge, as it consists of more easily digestible carbohydrates and fats, compared to activated sludge, which consists of complex carbohydrates, proteins, and long chain hydrocarbons. Thus, not only that the biogas is more easily produced from primary sludge, its energy content compared to excess secondary sludge is also very high. Thus, wherever any energy generation unit based on anaerobic digestion of sludge exists in an STP, any extra removal of suspended organics from the primary clarifier can add greatly to the energy generation potential from the sludge [Hanjie, Z., 2010].

In addition to the settling property of sludge, the overall efficiency of the whole system for organics and nitrogen removal can be monitored and kinetics can be studied for best performance of the system.

The research work is mainly focused to use the available process data for improvement in process efficiency of secondary treatment unit and to achieve higher efficiency of primary clarifiers by which operating cost may be reduced.

## 2 METHODOLOGY

### 2.1 The Set up

#### 2.1.1 Location and Timing

The study was performed on two identical laboratory scale activated sludge systems located inside the PHE Laboratory, Department of Civil Engineering, MNIT, and Jaipur. The reactors were run for a few weeks at continuously decreasing HRT of 12 to 6 hours to establish steady state conditions. The experimental analysis was carried out for a period of six months from November 2014 to April 2015. All the reactors were fed with raw wastewater obtained from STP plant at MNIT, Jaipur.

#### 2.1.2 Reactors

The experimental set up comprised of the storage tank, peristaltic pumps, connecting silicon tubes, diffuser pumps, and settling tanks as shown in Fig.2.1. The storage tank was provided with a lid for keeping out the sewage smell as shown in Fig. 2-2(b).

**Figure 2.1: Experimental Setup**

##### 2.1.2.1 Reactor Design

Each setup consisted of two settling tanks, one aeration tank and two storage tanks for inlet and outlet. All the tanks were made of acrylic material. A peristaltic pump was used (Fig.2-2(a)) for pumping the water from inlet storage tank to PST and in rest of the system water flowed under gravity from PST to aeration tank and then to SST.

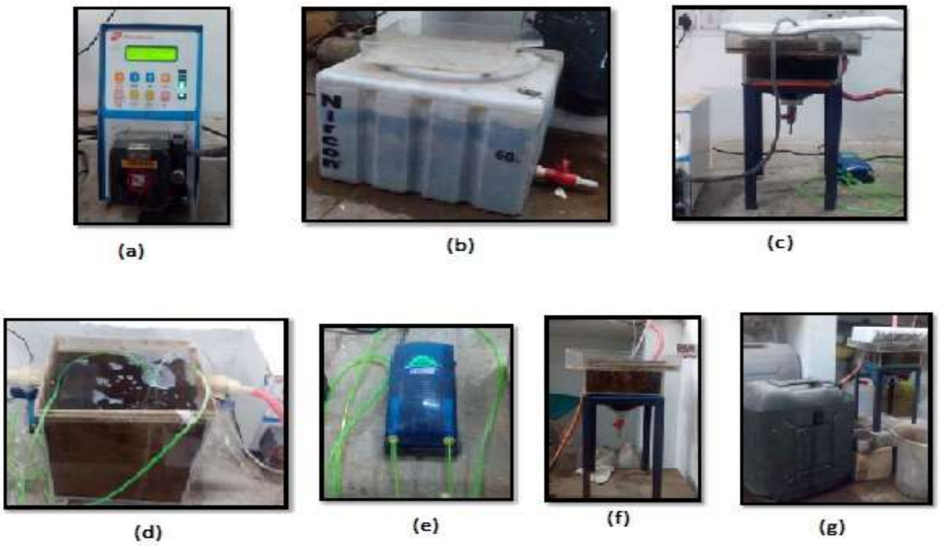


**Figure 2.2: Peristaltic Pump used for Pumping the Water from Inlet Storage Tank to PST, (b) Inlet Storage Tank used for Raw Wastewater Storage, (c) PST Tank in our ASP Setup, (d) Aeration Tank of Our ASP Setup Equipped with Diffuser Pumps, (e) Diffuser Pump for Providing Aeration in Aeration tank, (f) SST Tank Used in ASP setup, (g) Outlet Storage Tank in ASP Setup**

 

**Inlet Storage Tank (Sump):** A 60L acrylic tank (Fig.2-2(b)) was used as a storage tank for inlet raw water to be fed to the system. On daily basis, 60L raw water was brought from the STP plant located inside MNIT campus, Jaipur and poured into this tank. This storage tank was provided with an aerator with the limited diffusing power to facilitate only mixing in the tank so that minimum settling occurs in it. This also helped in curbing the smells.

**Primary Settling Tank (PST):** A 4.5L acrylic rectangular tank was used (Fig.2-2(c)) for primary settling. It was provided with a nozzle at the bottom for the collection of sludge. The raw water from the inlet storage tank was pumped into it with the help of peristaltic pump (Fig.2-2(a)).

**Aeration Tank:** A 14L acrylic rectangular tank (Fig, 2-2(d)) was fabricated for biological reaction to take place. It was provided with two aeration pumps (Fig.2-2(e)) to provide sufficient oxygen for biological action to take place. Commissioning of the reactor was carried out by bringing activated sludge from STP Delawas, Jaipur and added to the system in fixed quantities twice a day for a period of one week. After attaining pseudo steady state conditions characterized by MLSS, DO, SVI and COD of the system, it was run at different HRTs from 12 h to 6 h. The plant was operated for two weeks each at each HRT after ensuring that the pseudo steady state conditions were attained.

**Secondary Settling Tank (SST):** A 4.5L acrylic rectangular tank (Fig.2-2(f)) similar to PST was used for secondary settling. Similarly, it was provided with a nozzle at the bottom for the collection of sludge.

**Outlet Storage Tank:** A35L tank (Fig.2-2(g)) was used for collection of outlet water for testing purpose.

The assembly of reactors was done into laboratory scale activated sludge system. The reactors were commissioned using secondary sludge brought from STP Delawas and run on HRT of 12 h and allowed to attain pseudo steady state conditions exemplified by three consecutive readings of COD, MLSS, SVI, DO having a standard deviation less than 10%. The reactors were run for a few weeks at continuously decreasing HRT of 12 to 6 hours to establish steady state conditions. The organic and nitrogen removal was studied at different stages. The relationship between particle size distribution and overflow rate was addressed in a study [Patry et al., 1992]. Different water quality parameters such as BOD filtered BOD, TSS, COD, filtered COD, $NO_3^-$-N, ammonical nitrogen, TKN were studied at all stages.

After the successful commissioning of the reactor at a hydraulic retention time of 6 hours, the proportion of recycling of activated sludge to PST and AT was changed as shown below:

| S.N. | Primary Settling Tank (PST) | Aeration Tank(AT) |
|---|---|---|
| 1. | 0% | 70% |
| 2. | 10% | 60% |
| 3. | 20% | 50% |
| 4. | 30% | 40% |
| 5. | 40% | 30% |
| 6. | 50% | 20% |
| 7. | 60% | 10% |

The study has demonstrated that sludge recycling is a viable technology for improving the primary treatment efficiency [Huang et al., 2000]. It was seen that the effects of HRT and the sludge recycle ratio as a parameter affected the removal efficiency of COD and SVI value in an aerobic activated sludge system. The COD removal was seen to increase with an increase of recycled sludge ratio [Hosseini et al., 2008]. At each HRT the reactor was run for 10 days, which was more than 15 times the HRT generally recommended for achieving pseudo steady state conditions. The pseudo steady conditions were assumed to establish when the readings were constant having about 10% SD which was normally achieved after 7 days. Hence, the reported results indicate the mean and SD values of at least three consecutive readings**.**

After the successful commissioning of the reactor, COD (filtered and non-filtered), BOD (filtered and non-filtered), SVI, MLSS, suspended solids were monitored continuously as per (APHA, Standard Methods for the Examination of Water and Wastewater 1999).

 

## 3. RESULTS

### 2.2 Characterization of sewage and commissioning of reactors with 50% recycling of activated sludge:

COD results of setup A and B during their commissioning are as shown in the Fig. 3-1 and 3-2 respectively.

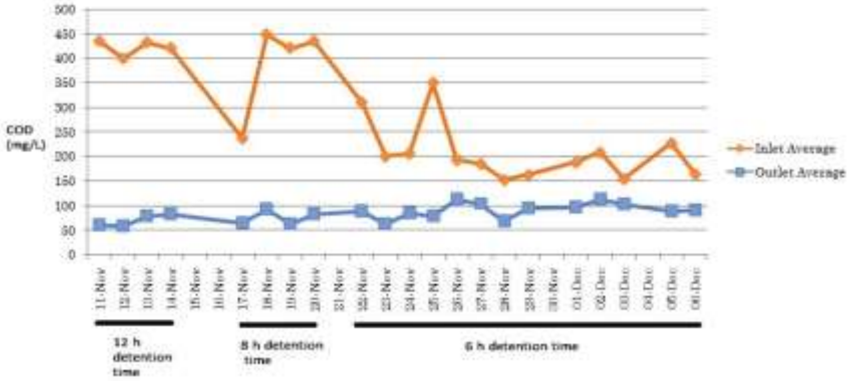


**Figure 3.1: COD analysis of Setup A at 50% Recycling of Activated Sludge**

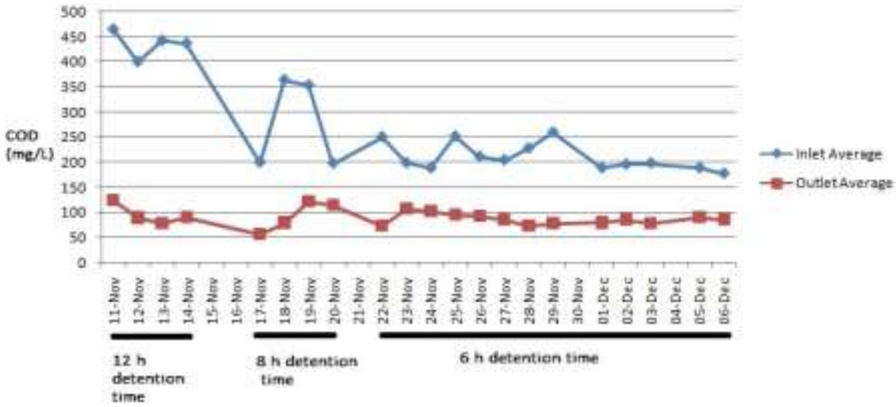


**Figure 3.2: COD Analysis of Setup B at 50% Recycling of Activated Sludge**

It can be analyzed from these results that despite large fluctuations in inlet COD ranging from 150 mg/l to 450 mg/l, the outlet COD was almost constant ranging from 50 mg/l to 100mg/l and in the last 5 days when the setup was running at 6h HRT, the outlet COD values were stabilized considerably. The performance behaviour of both the set ups was also quite similar.


**Figure 3.3: MLSS Results at 50% Recycling**

It can be seen in Fig. 3-3 that MLSS is continuously decreasing. It was stabilized at a low value of about 500 mg/L and hence it was felt that this recycle ratio may not be appropriate to run the reactors at good efficiency levels. It was thus shifted to 70 % recycle of biomass with the remaining 30 % being wasted.

 

### 2.3 Stabilization at 70% Recycling of Activated Sludge

The performance behaviour of the reactors at 70 % recycling is depicted in figure 8 for different parameters and the settleability was also found to improve significantly as evidenced visually by changing the recycling ratio from 50% to 70%. All further experiments were carried out at an overall recycle ratio of 70% only. The COD measurements at 70% recycling of both the setups indicated an improved performance compared to the previous conditions.

After commissioning of the reactor at 70% recycling of activated sludge in the aeration tank, the ratio of the recycling was changed in PST and AT from 0% in PST and 70% in AT to 60% in PST and 10% in AT. All through the experiments, the DO levels were observed to vary between 3-4.5 ppm ensuring aerobic conditions prevailing throughout the reactor operation even within the micro environment of flocs.

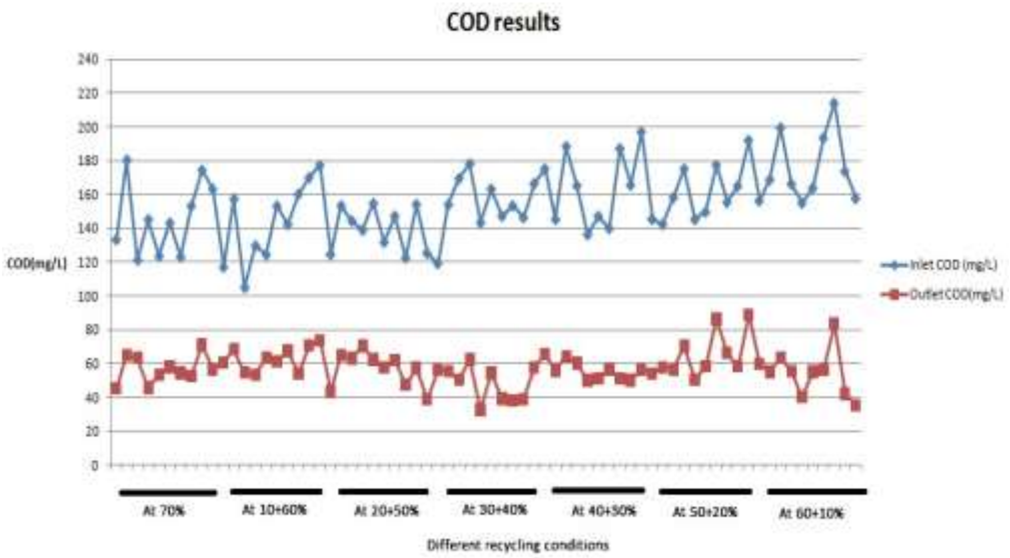


**Figure 3.4: Daily Results of Inlet and Outlet COD**

The figure 3-4 shows the daily results of COD after commissioning of the reactor at 70% recycling of activated sludge.

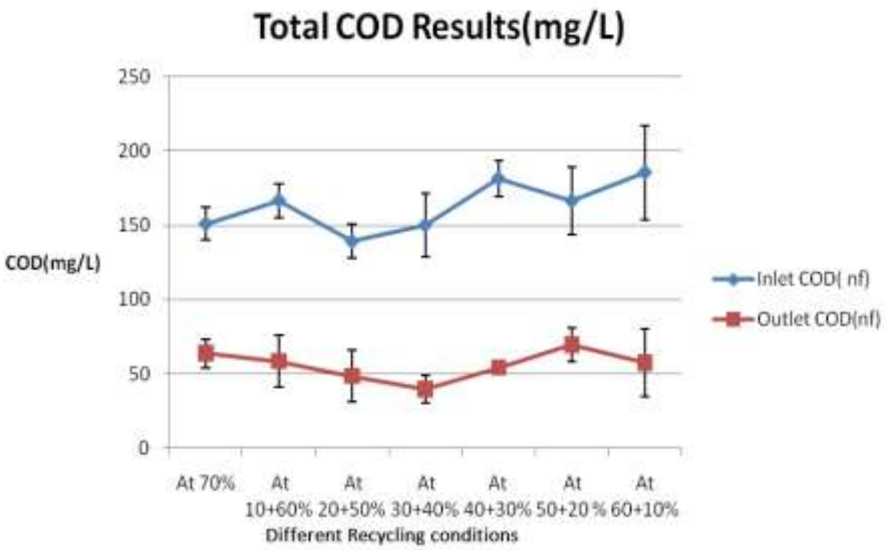


**Figure 3.5: Total Inlet and Outlet COD Results in all Recycling Conditions**

This Fig.3.5 Depicts the mean values of inlet and outlet COD with error bars. It can be seen from this graph that minimum outlet COD was achieved at 30+40% recycling conditions.

 

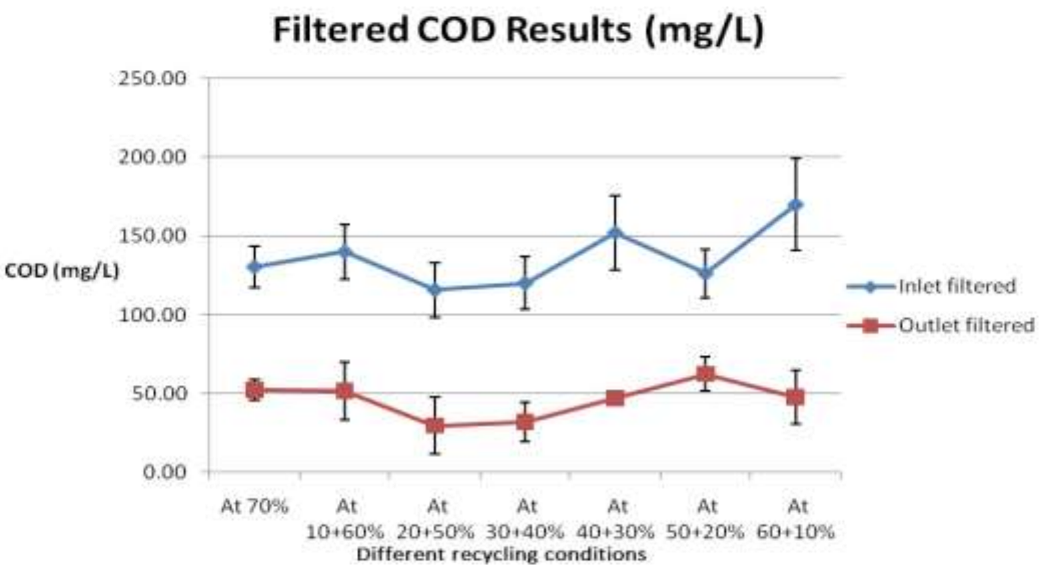


**Figure 3.6: Filtered Inlet and Outlet COD at all Recycling Conditions**

For filtered COD, results similar to non filtered COD were observed and minimum COD was achieved at 30+40% recycling condition in spite of large fluctuations in inlet COD as shown in Fig. 3-6.

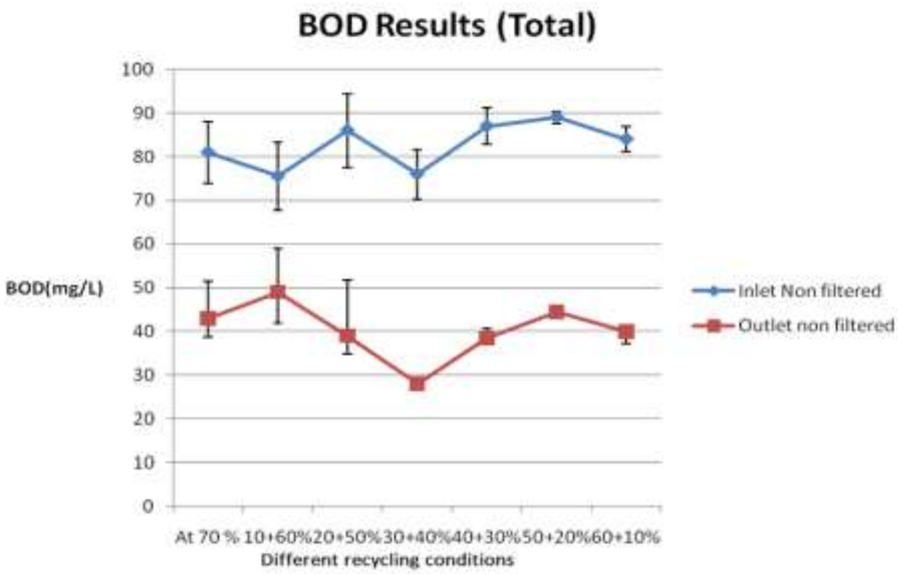


**Figure 3.7: Pseudo Steady State BOD Values of Total Inlet and Outlet at Different Recycle Conditions**

The Fig.3-7 shows the mean BOD values at all recycling conditions. Also, it can be seen that minimum outlet BOD is achieved at 30+40% recycling condition.

 

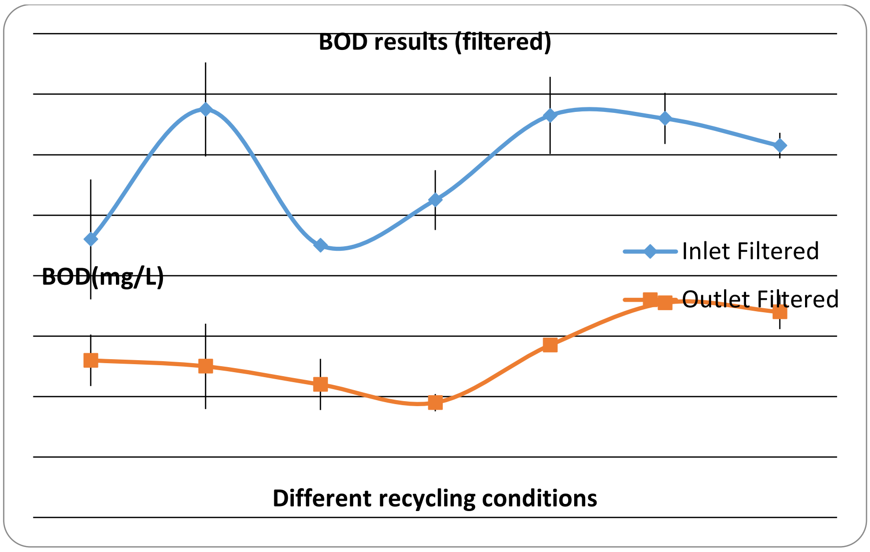


**Figure 3.8: Filtered Inlet and Outlet BOD at Different Recycle Conditions**

The Fig. 3.8 shows the mean filtered BOD values at all the recycling conditions and minimum filtered BOD was achieved at 30+40% recycling condition.

It was observed from COD and BOD measurements that maximum removal efficiency in the system was achieved at 30%+40% recycling ratio, that is, out of 70 % activated sludge to be recycled, 30% was sent to the PST and 40% was sent to the AT. At all these ratios, MLSS of aeration tank varied between 1060 and 1250 as shown in the Fig.3-9.

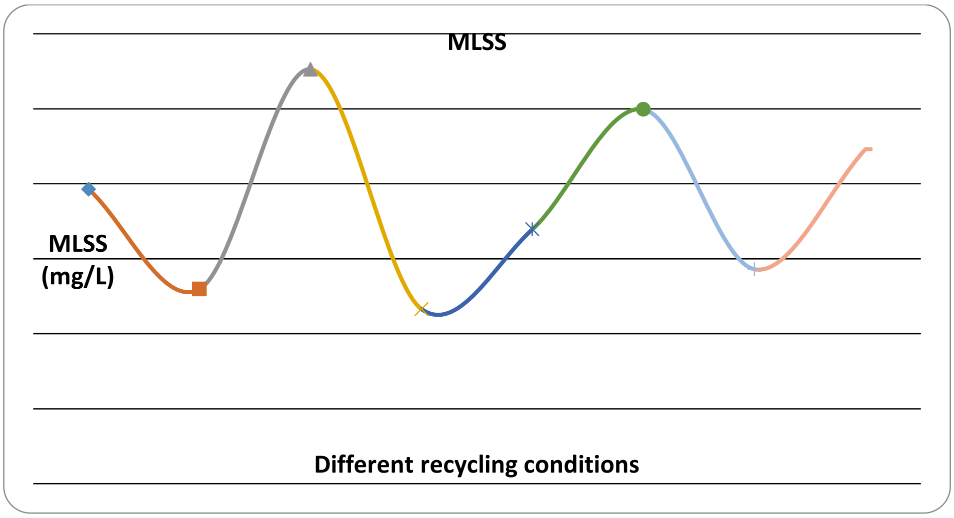


**Figure 3.9: MLSS at Different Recycling Ratios**

At all these given ratios, sludge volume index (SVI) varied between 25mg/l and 35mg/l as shown in the Fig. 3-10.

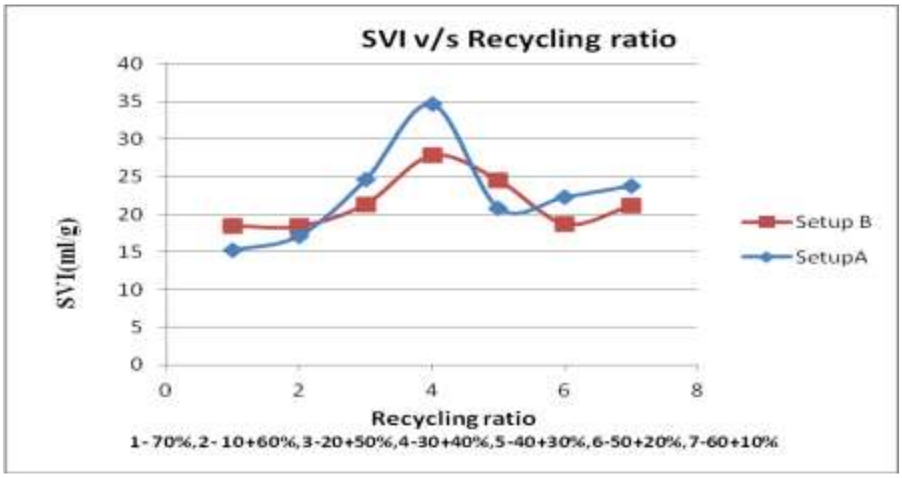


**Figure 3.10: SVI at Different Recycling Ratios (Setup A, B)**

The results shown in Fig.3-10 indicate that as the recycle ratios are increased the value of sludge volume index also increases. Point 4 in Fig. 14 shows the maximum value (25-35mg/l) at 30+40 recycle ratio. After this recycle ratio value of SVI starts decreasing in both setups means 30+40% recycle ratio is most prominent recycle ratio and system gives the highest value of SVI representing an interesting fact that the system throughout indicates the prevalence of pin point flocculation and this increase in SVI is, in a way, is good for the system.

## 2.4 ORGANIC REMOVAL AT ALL RECYCLING CONDITIONS

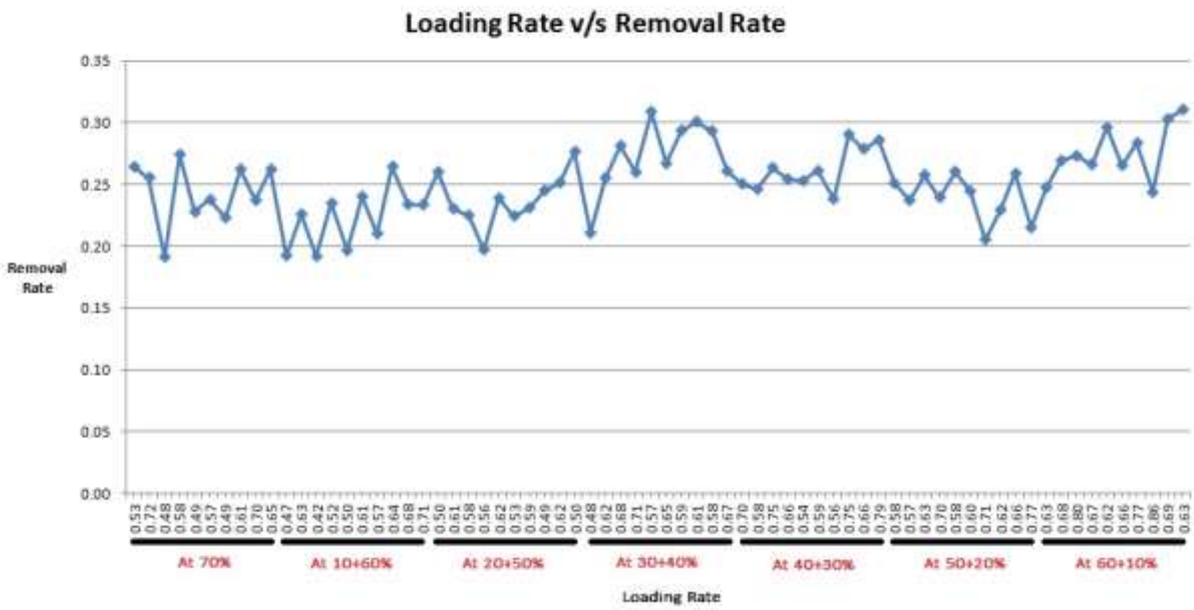


**Figure 3.11: Loading Rate v/s Removal Rate after Commissioning at 70% Recycling Condition**

The loading rate v/s removal rate is plotted in Fig.3-11. It can be seen from this zero order graph that in spite of fluctuations in inlet COD, removal rate was more or less constant throughout the system. This explains that our system was able to adjust to all the conditions satisfactorily and organic removal was almost complete. It was on expected lines as the incoming BOD is rather low due to liberal use of water in the institute.

 

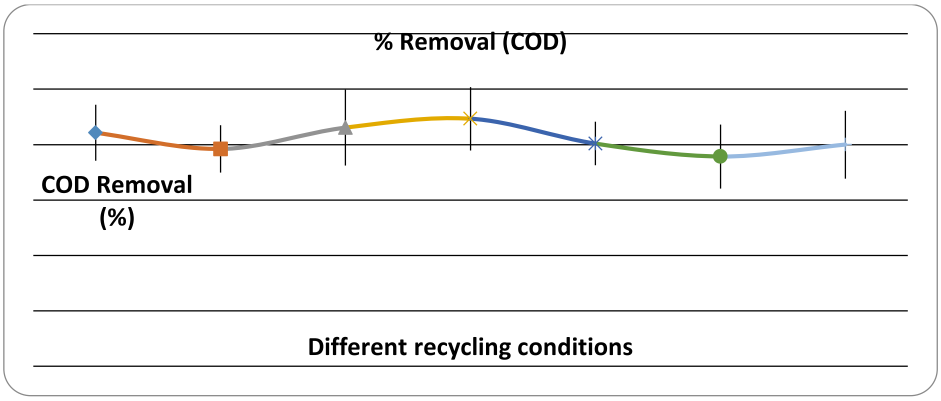


**Figure 3-12: Percentage Removal of COD at all Recycling Conditions**

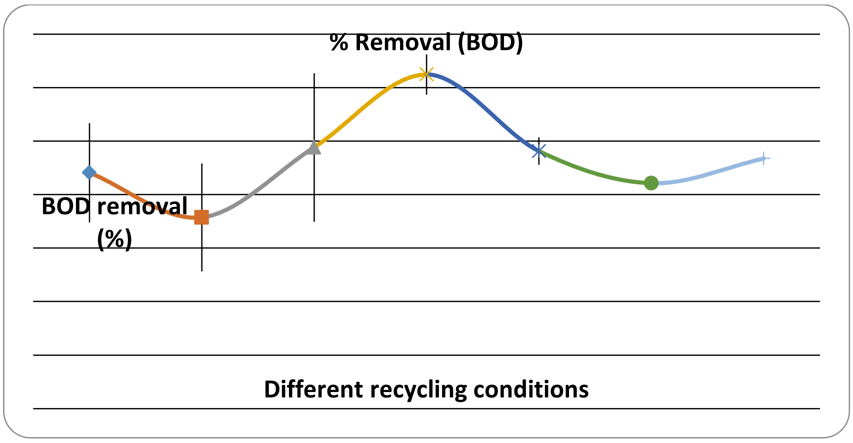


**Figure 3-13: BOD %Removal at Different Recycle Ratios**

It can be observed in Fig. 3-12 and Fig.3-13 that maximum removal of COD and BOD was achieved at 4$^{th}$ recycling condition, that is, 30% recycling in PST and 40% recycling in AT. These results depict the relationship between organic loading v/s removal percentages in term of COD, BOD. In these graphs we observed that organic loading rate different recycling ratio is almost constant and percentage removal of BOD and COD in both graphs is maximum at 30+40% recycling ratio that is, out of 70 % activated sludge to be recycled, 30% was sent to the PST and 40% was sent to the AT. The maximum COD removal efficiency was observed as 81.29% for organic loading rate 0.4497 Kg/day/m$^3$ and the maximum $BOD_5$ removal efficiency was attained as 65.11% for an organic loading 0.2879 Kg/day/m$^3$. Fig.3-12 and Fig.3-13 show that the reactor was able to work well when the BOD loading is in the range of (0.15 – 0.3599) kg BOD/day/m$^3$, which is quite good compared to the high rate ASP i.e. (1.5 –3.5) kg BOD/day/m$^3$ as reported by Gray (1989). It shows that at 30+40% recycling ratio system remove maximum organic load or work more efficiently at this ratio. The extra removal of COD and BOD was about 5.9% and 42% higher respectively than that of the conventional scheme with recycling to the AT only. This further means that a similar oxygen demand will not be exerted in the AT and hence derive double benefit. This could have been further higher if the strength of the sewage was more as the raw sewage COD/BOD are much less in the present study. In a conventional ASP, in 6 hour HRT, normally COD/BOD removal rates would be much higher but here carbon limiting conditions are apparently prevailing.

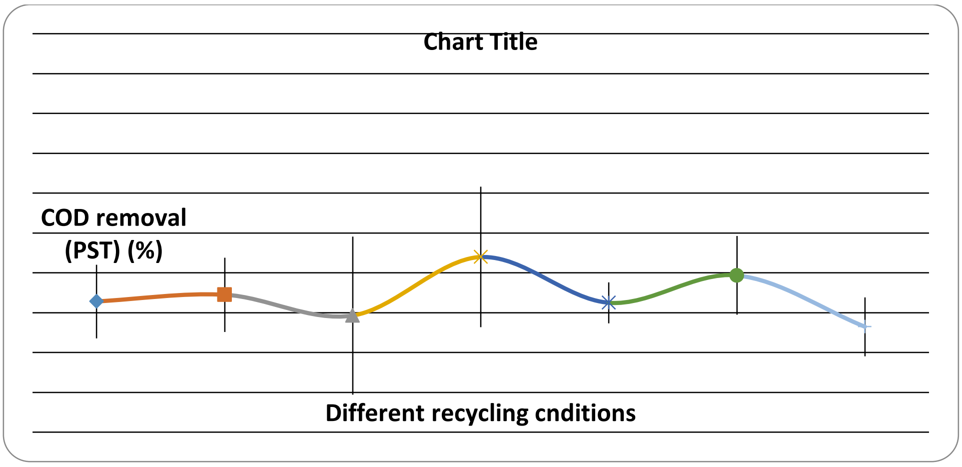


**Figure 3.14: % COD Removal in PST at all Recycle Ratios**

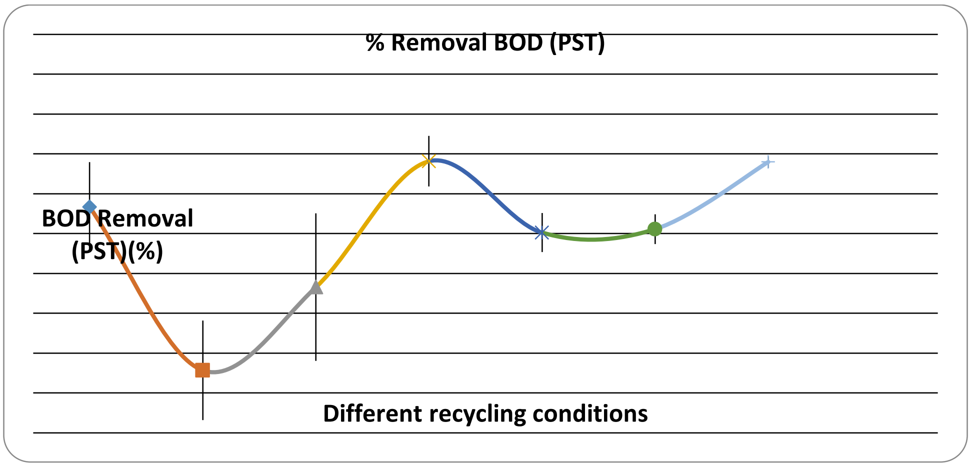


**Figure 3.15: % BOD Removal in PST at all Recycle Ratios**

It can be observed in Fig.3-14 and Fig.3-15 that as the recycle ratio is increased the removal rate of primary settling tank increases. It is seen that maximum removal percentage (21.99%) of COD and maximum removal percentage (34.08%) of BOD in PST was achieved at 4$^{th}$ recycling condition, that is, 30% recycling in PST and 40% recycling in AT. It shows that at 30+40% recycling ratio system remove maximum organic load or work more efficiently at this ratio.

## 3 CONCLUSION

The major conclusions derived from the study and data analysis are as follows:

1. It was seen that the rate of return sludge at 50% was not efficient in a laboratory setup. MLSS was seen to continuously decrease and stabilize at a value of 500mg/L. Hence, it was not suggested to run the reactor at this recycling ratio, so the ratio was shifted from 50% to 70%. At this rate of return sludge, the setups were seen to maintain suitable biomass. Hence, the further analysis was carried at this rate of return sludge.
2. It was seen that out of all the seven recycling conditions (PST+AT: 0+70%, 10+60%, 20+50%, 30+40%, 40+30%, 50+20%, 60+10%), the performance of the setup was the best at 30+40% recycling condition in terms of organics removal when 30% of the activated SST sludge was recycled to PST and 40% to aeration tank whereas 30% was wasted.
3. The organic removal followed a zero order variation indicating that almost all biodegradable organics were oxidized and the system was operating at low organic loads. The average organic loading and removal rates ranged around 0.60 kg of COD applied per day per unit volume and 0.25 kg of COD removed per day per unit volume respectively and the effluent COD values ranged between 25 to 80 mg/L, which were within the norms for effluent discharge in to surface water bodies (CPCB standards). Compared to the conventional control (all recycled biomass going to AT), the improvement in organics removal in the system was 38% at 30+40% recycle combination.

 

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