A SHIFT FROM ACTIVATED SLUDGE PROCESS TO UPFLOW SLUDGE BLANKET FILTRATION – A Review

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ABSTRACT

The detrimental effects of industrial and domestic wastewater discharge to the environment is of exigent concern with reference to the ecological impact on biota. In this regard, management of wastewater to produce effluent with the best quality is imperative and technology selection criteria requires a process that is not only cost-effective for a community but also environment friendly. USBF (Upflow Sludge Blanket Filtration) is an influential modification of the activated sludge process and extends over the treatment of wastewater using agglomeration processes for transformation of colloidal and dissolved impurities in water into separable floc suspension. It develops in a system divided into interconnected zones where primary sedimentation, nitrification-denitrification and clarification takes place. The conditions that put this process in a favourable position are single-tank configuration, small foot print, self-regulating hydraulic flexibility, alkalinity recovery, easily expandable and low capital costs. By dint of its performance, this system at optimal operating conditions can be effective for wastewater treatment.

Keywords: Activated sludge, biota, nitrification-denitrification, USBF, self-regulating

INTRODUCTION

Contemporary statute put forward for wastewater treatment has led to formulation of high grade quality effluent. Eventually, this had subsidizing effects of human negligence towards environmental safety and escalated the demands on superior technologies. In 1914, Edward Arden and W. T. Lockett (England) proposed an idea on Activated Sludge Process (ASP) which is an aerobic suspended-growth treatment system comprising of an aeration tank and a clarifier-settler. [42] It involves the production of an activated mass of microorganisms, which includes a diverse community of heterotrophs and autotrophs, capable of stabilizing waste aerobically and to remove organic carbon and nutrients present in wastewater. The major hindrance that depletes the efficiency of the process is the high sludge age that is used for nitrification which deteriorates sludge digestion.In order to address this impediment, an advanced radical design is integrated into the system. This revamp of the ASP is termed Upflow Sludge Blanket Filtration (USBF). On analogizing, the activated sludge process provides moderate removal efficiency than USBF for COD, BOD and TSS. Inorder to overcome certain limitations of the ASP system such as hydraulic flexibility, abrupt changes in the characteristics of wastewater or in its working volume, the USBF system. [21, 33] The process such as UV treatment, Reverse Osmosis, Enzyme filtration process and ion exchange or vacuum distillation (for the removal of oil and grease) can be employed for further treatment of waste water so that it can also be used for drinking purposes.

TREATMENT PATHWAYS IN ETP Various stages of treatment of wastewater before effective discharge are as follows: 1) Initial processing and primary treatment, 2) Secondary treatment and 3) Tertiary (or advanced) treatment. Initial processing and primary treatment involves physical separation of coarse solids, fine solids and other large-sized materials (organic and inorganic) like cloth, plastics, wood logs, paper, etc. This is a vital factor to enhance the operation and maintenance of the subsequent units. [38, 10]. Common unit operations include: 1) Screening: using meshes of uniform size is used to remove large solids such as plastics, cloth etc. (Usually, 10mm is used). 2) Sedimentation: Physical water treatment process using gravity to remove suspended solids from water. 3) Clarification: Deals with separation of solids from fluids. Common unit processes include: 1) pH Control: To adjust the pH of wastewater to specific standards in the treatment process. For acidic wastes (low pH), NaOH, Na_2CO_3, $CaCO_3$ or $Ca(OH)_2$ is used and for alkali wastes (high pH), H_2SO_4 or HCl is used. 2) Chemical coagulation: Process used to neutralize charges and form a gelatinous mass to trap (or bridge) particles, thus, forming a mass large enough to settle or be trapped in the filter. Chemical coagulants like $Al_2(SO_4)_3$ (also called alum) or $Fe_2(SO_4)_3$ are added to wastewater to improve the attraction among fine particles so that they come together and form larger particles called flocs. 3) Flocculation: Refers to gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from solution.

A chemical flocculent (usually a polyelectrolyte) enhances the flocculation process by bringing together particles to form larger flocs, which settle out more quickly.

In secondary treatment biological and chemical processes are involved that may be used to remove or reduce the concentration of organic and inorganic compounds. When certain effluents require only aerobic processes for treating, others necessitate collaborative effects of both aerobic and anaerobic processes.[20] Aerobic treatment processes take place in the presence of air (oxygen), utilizes those microorganisms (aerobes), which use molecular/free oxygen to assimilate organic impurities and convert them to carbon dioxide, water and biomass. Anaerobic treatment processes take place in the absence of air (oxygen) utilizing microorganisms (anaerobes) which do not require air (molecular/free oxygen) to assimilate organic impurities. Common high-rate processes include the activated sludge processes, trickling filters or biofilters, oxidation ditches, and rotating biological contactors (RBC). A mix of these processes in series (e.g., biofilter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources.[31, 39]

Tertiary / Advanced Treatment includes intensive cleaning process that ameliorates wastewater quality before it is reused, recycled or discharged to the environment. Mechanism involves removing the remaining inorganic compounds, and substances, such as the nitrogen and phosphorus, bacteria, viruses and parasites, which are harmful to public health. [40] Alums are used to help remove additional phosphorus particles and group the remaining solids together for easy removal in the filters. Chlorine contact tank disinfects the tertiary treated wastewater by removing microorganisms in treated wastewater. The remaining chlorine is removed by adding sodium bisulphate just before it's discharged. [12, 13]

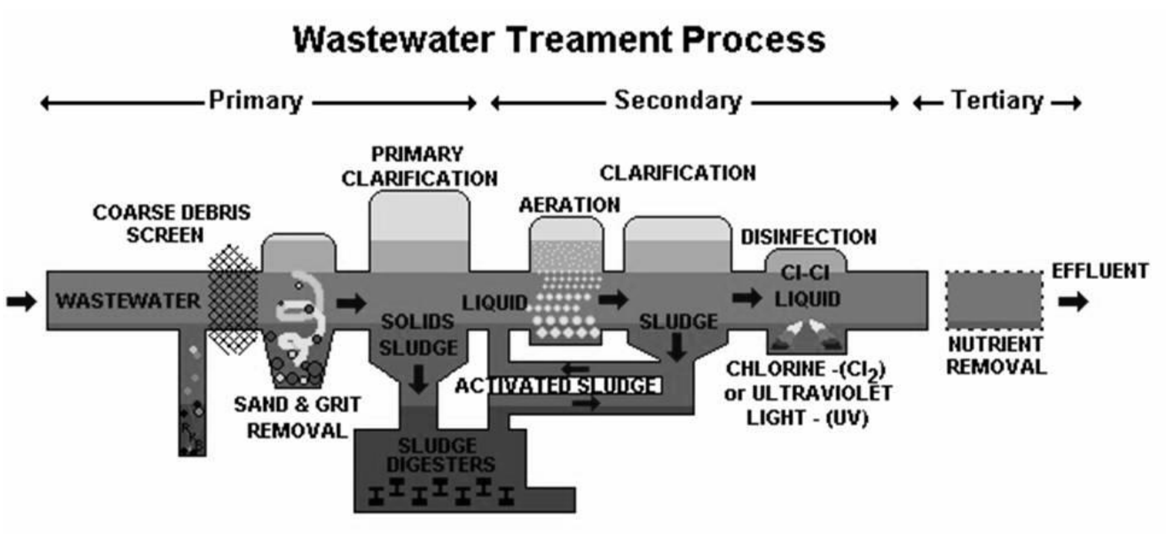

Fig 1: Wastewater treatment process stages

INNOVATIVE NECESSITIES IN WASTEWATER TREATMENT

The concurrent effects of agricultural escalation, industrialization and urbanization has led to alarming water shortage issues. Thereby, most of the river basins are closing or have already been closed. Performance criterion evaluated for the state-owned sewage treatment plants (STP) and common effluent treatment plants (ETP) for processing municipal wastewater and other effluents from various small scale industries is also negligent in terms of prescribed standards. Thus, the development of innovative technologies for treatment of wastewaters from various industries is a matter of significant concern for us.

In view of the fact that the efficiency of the solids/liquids separation is mainly influenced by the properties of the sludge, Edward Arden and W. T. Lockett (England - 1914) proposed an idea on Activated Sludge Process (ASP) which was expanded as an intermittent to biological filters, and is particularly beneficial for large populations where land is at a premium. In the later days of their work, they apprised that the defined system had significant reduction of biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) and total dissolved solids (TDS) with high percentage removal of nutrients and toxic materials like nitrate, phosphate etc.

ACTIVATED SLUDGE PROCESS (ASP)

Microorganisms impart a notable role in the purification of wastewater by converting biodegradable organic matter to forms that are able to ensure the stability of wastewater while some are pathogenic. Basically, in systems such as rivers and streams, these water bodies possess a kind of self-purification ability, with the support of microorganisms-based-activities. These abilities have been overwhelmed by pollution, hence, technological enhancements were urged. ASP is a unit process comprising of suspended growth of microorganisms (both living and dead) activated by supply of air and therby decreasing carbonaceous pollution. Activate-sludge is that sludge which settles down in a secondary sedimentation tank after the effluent has been freely aerated and agitated for a certain time. The process comprises 3 components: 1) Aeration tank 2) Sedimentation tank or clarifier 3) Recycler system

Process is initiated by confining naturally-occurring microorganisms present in wastewater at higher concentrations in the aeration tank. Aeration has two major motives which includes supplying the required oxygen to the organisms to grow and providing optimum contact between the dissolved and suspended organic matter and the microorganisms. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. The suspension of wastewater and microorganisms make the mixed liquor. The microbes consume organic carbon molecules and as a result, they flourish, and the wastewater quality is improvised. Following the aeration step, the microorganisms are separated from the effluent by sedimentation and the clarified liquid is the secondary effluent. A portion of the biological sludge is recycled to the aeration basin through a recycler system to maintain a high mixed-liquor suspended solids level. The remnants are removed from the process and sent for sludge processing to maintain a relatively constant concentration of microorganisms in the system. The treated wastewater or effluent can then be discharged to arriving waters – normally a river or the sea. [5, 48]

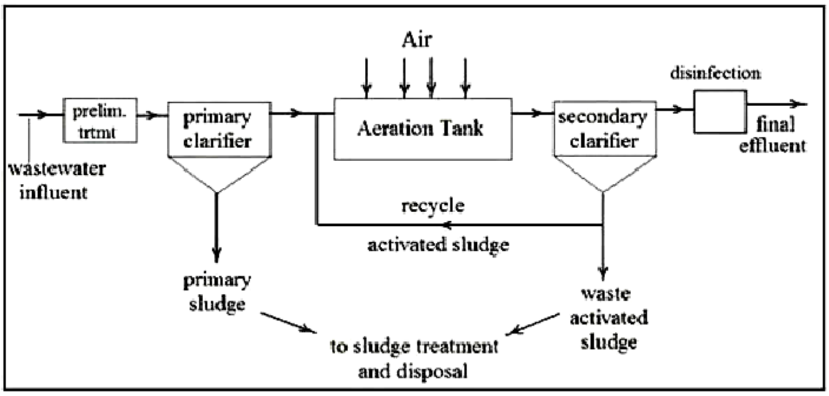

Fig 2: ASP flow diagram

The presence of bacteria such as Nitrosomonas, Nitrococcus, and Nitrobacter drives the nitrification and Pseudomonas, Micrococcus, Bacillus and Alcaligenes are involved in the denitrification process. In order to maintain sufficient nitrification rate in the ASP, dissolved oxygen (DO) concentration has to be maintained at 1.5 to 2 mg/L and alkalinity at the level of at least 1 - 1.5 mmol/L. The ASP can also be used for perform phosphorus removal by chemical precipitation. Bacteria such as Acinetobacter spp. also perform phosphorus removal by storing phosphorus as an energy reserve. [19] The ASP has been described as efficient in metabolizing a vast number of organic compounds and to oxidize or reduce polymerized compounds containing nitrogen, phosphorus, sulfur etc.

Although the system is direct and uncomplicated, the control over the process is very abstruse because of certain variables that affect it. These embrace changes in the combinations of bacterial flora on the treatment tanks, changes in the effluent parameters passing into the plant (parameters like flow rate, chemical composition, pH and temperature) and toxic shock loadings. The ASP suffers poor primary clarification which causes plugging and foul odours. Hydraulic overload and nitrification leads to high effluent total suspended solids, high chlorine demand and low pH. These limitations effectively reduce the overall efficiency of the process. [2]

TRICKLING FILTERS

The emerging stress-induced environments led to an urge for development of the tricking filter process, primarily designed for BOD removal. This system has attracted a great deal of attention due to its ability to take advantages of a biofilm reactor.[3, 23] An attached growth process is carried out in the filter wherein the microbes responsible for purification are allowed to thrive on an inert packing material (mountainous rock, gravel, fibres and other non-reactive synthetic materials). [24]

Trickling filter is a cylindrical set-up in which the feed wastewater is distributed through a sprinkler from the top section. The oxygen requirement of the microbes is facilitated through air distribution in the void spaces by either natural draft or blowers. The biomass (biological slime) adhered to medium metabolizes the organics present in wastewater into new cellular material. As a result of increased thickness of the slime layer, oxygen fails to penetrate the medium face and eventually, anaerobic organisms develop. The microbes growing near the surface of media loses the ability to attach on the same. The slime is then washed off by the feed and a new slime layer begins to grow. This phenomena of slime layer loss is termed as sloughing.The sloughed off film and treated wastewater are collected by an underdrainage which also allows circulation of air through filter. The collected liquid is passed to a settling tank used for solid- liquid separation.[14, 45, 50] Trickling filters prove better utilization of footprint and is simply reliable corresponding to significant reductions in BOD.

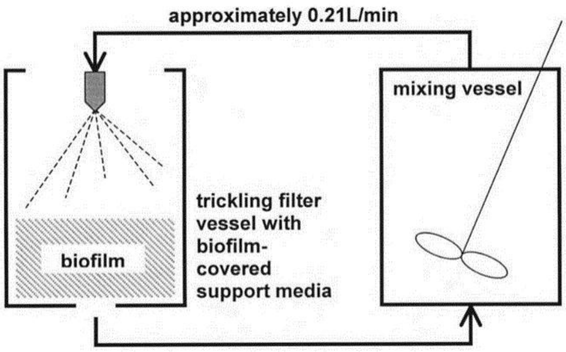

Fig 3: Aerobic trickling filter schematic [47]

Lately,efforts have been made to fuse fixed-film reactors with suspended growth processes to efficiently remove organic materials from wastewater. For example, the combination of a trickling filter with an activated-sludge process has allowed for the elimination of shock loads to the more sensitive activated sludge while providing a highly polished effluent that could not be achieved by a trickling filter alone. However, accumulation of excess biomass that cannot retain an aerobic condition dwells and can relatively impair the filter performance (maximum biomass thickness is controlled by hydraulic dosage rate, type of media, type of organic matter, temperature and nature of the biological growth). [25, 28]

Inorder to address the limitations faced by the activated sludge process and trickling filters, a revolutionary new wastewater treatment plant design concept was developed and named 'Upflow Sludge Blanket Filtration (USBF)'. [34] This system uses the whole spectrum of physical, chemical and biological treatments to reduce the toxic content of wastewater.

UPFLOW SLUDGE BLANKET FILTRATION (USBF)

USBF is a bioreactor that involves aerobic-anaerobic process. Figure 4 represents the schematic overview of the whole process. The removal of toxic compounds is typically done through biological processes by activated sludge. It is a reduced footprint single-tank configuration system comprising of 3 zones: anoxic/anaerobic zone, oxic/aerobic zone and clarifying zone. [30]

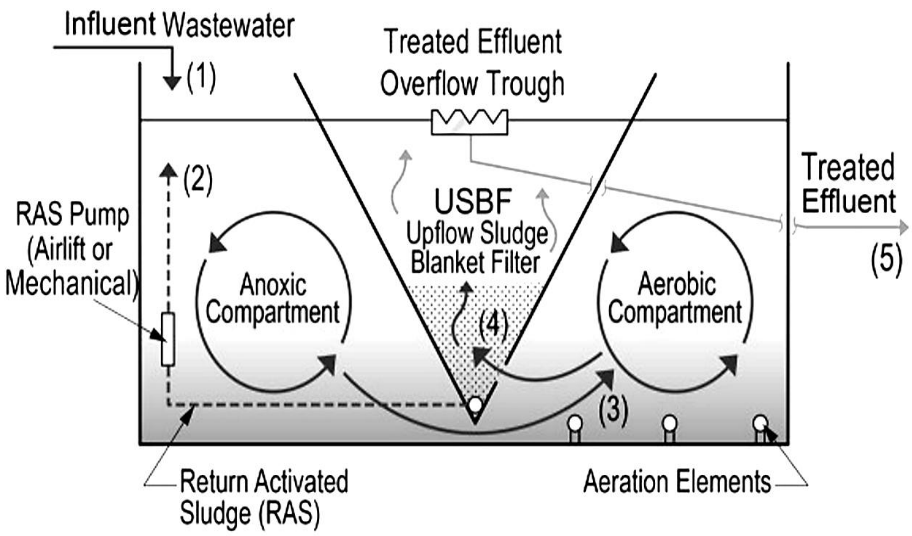

Fig 4: Schematic overview of USBF process

In anoxic zone, the influent (wastewater) is introduced in the anaerobic zone where it mixes with activated sludge recycled from the bottom of the sludge blanket filter. Here, primary sedimentation and denitrification occurs. About 60% - 70% reduction in the total suspended solids (TSS) concentration is anticipated in this zone. Here, nitrate reduction takes place which is microbially expedited through denitrifiers (Thiobacillusdenitrificans, Micrococcus denitrificans, Achromobacter, Pseudomonas aeruginosa etc.) and molecular nitrogen is produced. Agitated and moved in a plug flow manner, the mixed liquor flows into the aerobic compartment.

$$\text{Denitrification:} NO^{3-} \rightarrow NO^{2-} \rightarrow NO + N_2O \rightarrow N_2 \text{ (g)}$$

In oxic zone, the denitrified wastewater is subjected to aeration and simultaneously nitrification occurs. The 2 step reaction wherein ammonia/ammonium ions present are initially converted to nitrites which is facilitated by nitrifying bacteria (Nitrosomonas, Nitrosospira, Nitrosococcus, Nitrosolobus). Progressing, the nitrites is converted to nitrates which is facilitated by nitrifying bacteria (Nitrobacter, Nitrospina, Nitrococcus). After aeration, mixture of microbial cells and water enters the USBF filter at the bottom.

$$\text{Nitrification: } 2\ NH_4^+ + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4\ H^+$$
$$2\ NO^{2-} + O_2 \rightarrow 2\ NO^{3-}$$

In clarifying zone, the trapezoidal shape put together by the slots deliver continuous removal of fine solids (sludge formation). The dissimilitude in flocculation velocities in the lower and upper section due to increase in cross sectional area helps the particles to settle at their own specific velocities and thereby, forming a sludge blanket. No longer supported by the decreased upward velocity, the flocs of cells become stationary and thus form a filtering media themselves. Becoming larger and heavier by contact and agglomeration, the flocs eventually descend to the bottom of the filter and are subsequently recycled back into the anoxic compartment. As wastewater rises within the filter, it overflows into the effluent overflow trough at the top and is discharged from the system. A high degree of filtering efficiency is achieved as even very fine particles are filtered out. [26]

Incoming nitrogen is removed by nitrification and denitrification processes. All USBF integrated bioreactors are designed for complete nitrification of ammonia to nitrate. The technology's single-sludge denitrification uses an endogenous carbon source to maintain the denitrifiers. Influent is mixed with recycled activated sludge in the anoxic compartment providing the carbon source needed for denitrification. Incoming phosphorus is reduced by biological phosphorus uptake where the cells store more energy in the form of phosphorus than needed for their survival. Unlike most other methods of clarification, the sludge blanket filter maintains oxide conditions, which enable phosphorus retention by the cells and its subsequent removal with excess sludge. [29]

DESIGN CONSIDERATIONS AND ITS PERFORMANCE CRITERION

The geometrical variables that influences the efficiency of the system are slope and slot of the diffuser (clarifying zone). There can be three different types of diffusers, a cone, longitudinal prism and toroidal prism. The longitudinal prism is the most conventional diffuser.

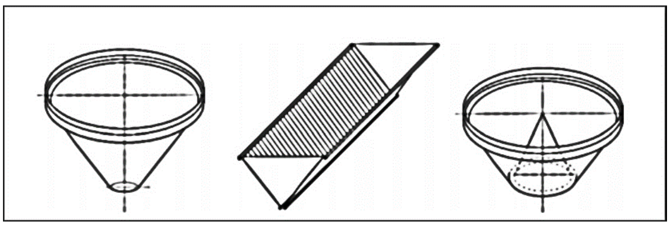

Fig 5: Diffuser types – cone (left), longitudinal prism (centre), toroidal prism (right) [4]

The slope influences flocculation, the fluid velocity and the forming of the sludge blankets. An upwardly widened shape is necessary because the velocity of the fluid has to decrease as it goes further into the diffuser. These differences in velocity are ideal for fluidization.

From the figure 6, the base level, Vs depicts free sedimentation velocity, above which the fluidized layer will distribute the velocity of the liquid. There has to be a minimum velocity of full fluidization, Vff, to get a fluidized bed filtration. On the top of the diffuser there has to be a minimum fluidizing velocity, Vmf. These velocities are necessary because the varying velocities will tend the particles to sediment at their own specific velocity and form a sludge blanket. When the slope is too small, the velocity in the x-axis (Vx in Figure 6) will push the particles to the walls and there will be sedimentation on the walls. This is inadmissible as it has an influence on the velocity and there won't be an equal velocity on one plane in the diffuser. [4, 15]

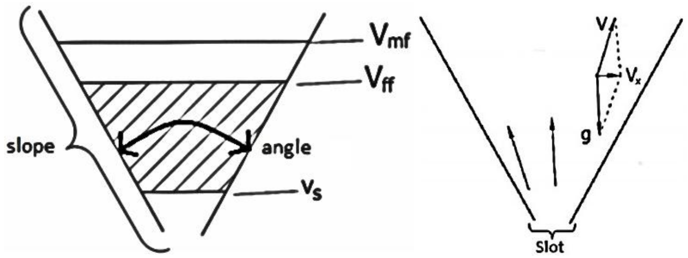

Fig 6: Schematic overview of fluidization in a diffuser – Slope, Slot [4]

The slot is another important geometric variable which facilitates formation of the sludge blankets and impacts the velocity of the fluid that enters the diffuser at the bottom. Velocity has significant effect on the formation of fluidized layers. When the slot is large, it is possible for the particles to fall through because of the gravitational forces, which results in no blanket at all and there will not be any considerable difference in decreasing velocity which has an influence on the forming the sludge blankets. Therefore, an optimal slot is indispensable.

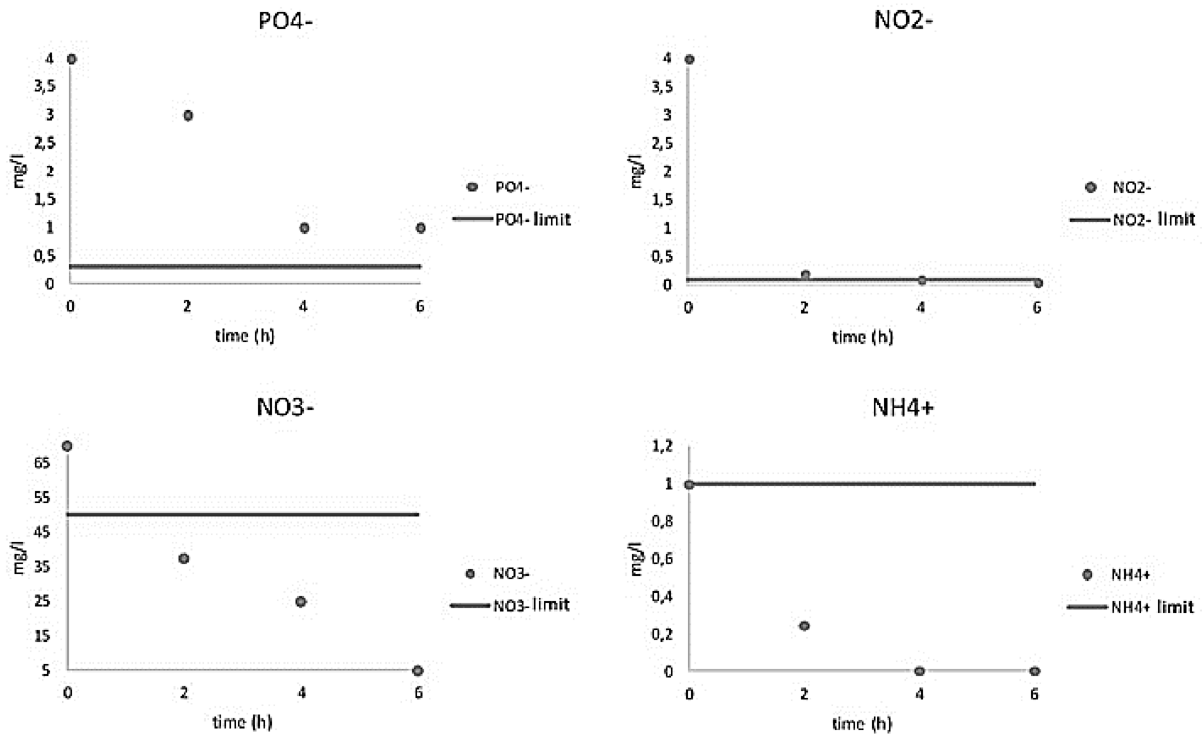

Fig 6: Decreasing concentration of nutrients of wastewater with respect to optimal slope angle of 52^{o} and slot 4 cm at 6 hrs hydraulic retention time [4]

BOD and COD of the final effluent at different HRT as low as 20 mg/l and 23 mg/l with their removal efficiencies up to 82% and 85% is attainable. The treatment analysis of BOD, COD, TSS, and turbidity of the effluent for different stages of wastewater treatment are shown in Table 1. In most cases, the TSS concentration in effluent had been less than 1 mg/l and one of the main reasons was formation of compact sludge clots in the sedimentation separators of the system. This phenomenon reduced the possibility of sludge escape from the system.

Operation stage	**Test/sample**	**1**	**2**	**3**	**4**	***Avg.***
Stage 1 (HRT = 6 h)	**BOD_5 (mg/l)**	25	22	24	20	***22.75***
	COD(mg/l)	28	25	27	23	***25.75***
	TSS(mg/l)	0.9	0.6	0.8	0.7	***0.75***
	Turbidity (NTU)	1.1	0.8	0.9	0.8	***0.9***
Stage 2 (HRT = 4 h)	**BOD_5 (mg/l)**	31	27	24	24	***26.25***
	COD(mg/l)	34	30	27	26	***29.25***
	TSS(mg/l)	0.9	0.8	1	0.9	***0.9***
	Turbidity (NTU)	1.5	1	1	1	***1.125***
Stage 3 (HRT = 2 h)	**BOD_5 (mg/l)**	120	145	155	148	***142***
	COD(mg/l)	132	160	170	162	***156***
	TSS(mg/l)	1.8	1.9	1.8	1.8	***1.825***
	Turbidity (NTU)	2	2.5	2	2	***2.125***
Stage 4 (HRT = 6 h by increasing influent BOD_5 and COD to 375 and 416 mg/l, respectively)	**BOD_5 (mg/l)**	32	31	30	30	***30.75***
	COD(mg/l)	36	35	34	33	***34.5***
	TSS(mg/l)	0.8	1	0.9	0.9	***0.9***
	Turbidity (NTU)	*1*	*1*	*1*	*1*	***1***

Raw wastewater: COD = 277 mg/l, BOD_5 = 250 mg/l

Table 1: Wastewater treatment analysis [4]

BENEFITS

USBF provides high treatment efficiency including biological nutrient removal. That is, the internal anoxic compartment provides the necessary conditions for dissimilarity nitrate reduction (denitrification) and phosphorus removal by "luxury uptake". [46] The integral denitrification process facilitates partial recovery of alkalinity loss during nitrification, and the anoxic compartment serves as a "selector zone" that conditions the mixed liquor to improve settleability and to control filamentous organism growth which leads to alkalinity recovery and filamentous bacteria control.

The odour is drastically reduced under aerobic conditions throughout the bioreactor and extended sludge age.The hydraulics in the bioreactor is self-regulated wherein it accommodates high peak flows and flow swings; the flow is proportional to the sludge blanket rise and larger is the filtration area. This is facilitated by the sludge filter's trapezoidal shape.Modularity of design allows to stage plant development and reduce initial capital costs. Even with a quick population growth, the modular nature of the system enables easy expansion. The sludge filters can be fabricated from a variety of materials, and they can be retrofitted into virtually any existing tank or reactor. [26, 29]

CONCLUSIONS

On analogizing, the activated sludge process provides lower removal efficiencies than USBF for COD, BOD TSS and TDS. Biological removal efficiency of nitrogen, phosphorus and preservation of sludge blanket strongly depend on wastewater characteristics, hydraulic retention time, sludge age and the overall process control. In order to overcome certain limitations of the ASP system such as hydraulic inflexibility, abrupt changes in the characteristics of wastewater or in its working volume, the USBF system is an apt preference. The feeding and draining can be conducted simultaneously for the USBF system with maximum volumetric exchange rate of about 80%. This in turn can lead to the reduction of the cycle time and increase in the utilization of the reactor volume. Although, the USBF bioreactor at the optimum conditions can be an effective technology for nutrient removal from municipal wastewater, it is not suggested for wastewater containing a high (Total Kjeldahl Nitrogen) TKN/COD ratio because of rising sludge and disordering blanket in the USBF clarifier. The optimization of hydraulic retension time is performed based on the effluent quality to avoid sludge rising due to denitrification process. Processes such as UV treatment, Reverse Osmosis, Enzyme filtration process and ion exchange or Vacuum distillation (for the removal of oil and grease) can be employed for further treatment of wastewater so that it can also be made potable. Therefore, this premier technology is an economic and reliable alternative for secondary wastewater treatment.

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