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Sequencing Batch Reactor as an Efficient Alternative to Wastewater Treatment– A Model From Pharmaceutical Industries

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ABSTRACT

Discharge of industrial wastewater to surface or groundwater pollutes the environment. Therefore, treatment of any kind of wastewater before letting it off as effluent is always necessary to prevent contamination of natural systems, especially water. In this regard choosing an effective treatment system assumes importance. Sequencing Batch Reactor (SBR) system has proven to offer substantial benefits to alternative conventional flow systems for the biological treatment of both domestic and industrial wastewaters. Operationally, SBR is extremely flexible in its ability to meet many different treatment objectives, while physically it is very simple. Sequencing batch (fill-and-draw) biological reactors can be operated to provide equalization, treatment, and sedimentation in the same set of reactors. The wastewaters can be held in the treatment systems until the desired effluent quality is achieved. The above results were obtained through the experiments carried out in a pharmaceutical industry. The effluents generated by the industry are pretreated and taken to evaporation system. The effluent condensate generated, containing organic load is taken to sequencing batch reactor for further treatment. The results are very encouraging and cost effective. This paper describes the SBR physical system and explains approaches to develop the design needed to meet different treatment objectives.

INTRODUCTION

The Sequencing Batch Reactor (SBR) is an activated sludge process designed to operate under non-steady state conditions. It operates in a true batch mode with aeration and sludge settlement, both occurring in the same tank. The major difference between SBR and conventional continuous-flow activated sludge system is that the SBR tank carries out the functions of equalization, aeration and sedimentation in a time sequence rather than in the conventional space sequence of continuous-flow systems. In addition, the Sequencing Batch Reactor system can be designed with the ability to treat a wide range of influent volumes, whereas the continuous system is based upon a fixed influent flow rate. Thus, there is a degree of flexibility associated with working in a time rather than in a space sequence. It is under these contexts, an innovative method has been adopted and tested for its operational utilities in a pharmaceutical industry. This paper explains the process involved in such treatments.

SBR system is a modified version of Activated Sludge Process. As in any activated sludge process, a mixed culture of bacteria capable of removing COD, BOD and nutrients are developed. The SBR is unique in its ability to act as an equalization basin, aeration basin and clarifier within a single basin. The system operates with proven simple sequences of fill, react, settle and decant in a single reactor configuration (Metcalf & Eddy 1991). In this reactor, sufficient oxygen is supplied to oxidize the organics, absorbed by the bacterial biomass. Required quantity of oxygen is supplied, and mixing is done by the diffused aeration system. The settled sludge at the bottom of the reactor is used to maintain the bacterial population in the reactor. The excess sludge is wasted periodically into the Sludge Drying Bed (SDB). The filtrate from the SDB is collected in filtrate collection sump and the filtrate is transferred to the SBR. The SBR is provided with a DO meter to check the dissolved oxygen level. Required quantities of urea and di-ammonium phosphate (DAP) are added manually.

ROLE OF DIFFUSED AERATION SYSTEM

The Diffused Aeration System (DAS) is comprised of ethylene propylene diene monomer (EPDM) membranes and polyvinyl chloride (PVC) pipe grid supported by reinforced concrete cement (RCC) ballasts at the bottom of the aeration tank. Air from the blowers at the desired rate having the required pressure is diffused through the DAS. The diffuser consists of a porous membrane of 1.0 m in length made of EPDM rubber/polyurethane material. Each diffuser is fully supported over full length and circumference with a 90 mm PVC membrane support frame (Eckenfelder et al. 1960), the diffuser is retained in place by stainless steel (SS) clips. Each diffuser is provided with a removable end cap to facilitate flushing of diffuser assembly for easy cleaning. The diffuser is fitted to the pipe laterally by a PVC flexible hose arrangement. The laterals are connected to a pipe header. The wetted parts of the system are made of non-corrosive material. During shut down conditions, the membrane will contract and close around the PVC support frame to prevent any back-flow. The diffuser is designed to ensure uniform permeability and to produce a flow of fine air bubbles approximately 2 mm in diameter. The fine uniform pore size ensures minimal head loss across the diffuser. Since the bubbles are of extremely small size, the total surface area that interfaces with liquid is large. The high contact area provided by the fine bubbles and the high contact time provided by the slow rise rate of the bubble makes this system very efficient in terms of oxygen transfer efficiency. The slow upward movement of the fine bubbles keeps the bottom of the tank clear of any settling deposits and also provides gentle mixing. The gentle uniform diffusion of air also prevents floc shear, which means flocs are larger in size and the settling times of the flocs are reduced. This results in increased efficiency of the clarifier and higher sludge concentrations.

AIR SUPPLY AND DISTRIBUTION

Air supply for the treatment plant is from single stage rotary positive displacement blowers or any other suitable blower. Inlet filters are fitted to the blower to effectively remove contaminants from the outside air. These contaminants may either be in the form of oil or other suspended particulate matter in atmospheric air. The air is distributed by a PVC piping manifold. The piping network is connected to headers. The pipes are supported and secured to the tank floor using RCC ballast.

BACTERIAL SEEDING

There are various methods for seeding culture into the SBR. The principal methods of seeding are (1) addition of substrate-specific bacterial culture, (2) addition of sludge from the re-circulation line of similar operating plant and, (3) addition of cow dung or other natural manure.

Addition of substrate-specific bacterial culture is a dry concentrate bacterial formulation, specifically designed to provide improved waste degradation for various types of wastewaters. In the second method the sludge is collected from the wastewater treatment plant of similar type of industry with respect to substrate. The sludge is collected as such in containers from the recirculation line of the plant, and added to the aeration tank (Irvine et at. 1989). It is recommended to add to sludge within 4-5 hours from the time of collection to avoid septicity and utilize the maximum amount of active culture. In the third method required quantities of fresh cow dung/manure is mixed with water to form slurry. The solids in the slurry are allowed to settle down. After 5 minutes of settling, the supernatant enriched with heterotrophic bacterial culture is transferred to the aeration tank. The exact quantity depends on the size of the plant and the inlet BOD and COD values.

ACCLIMATISATION OF MICROBIAL CULTURE

Acclimatisation is the time required for the microbial culture to get accustomed to the conditions present in the particular wastewater treatment plant (aeration tank) and carry out the process of bio-degradation of the substrate to the harmless final products, viz., water and carbon dioxide.

The time required for acclimatisation depends primarily on the factors like BOD and COD values, DO, pH, temperature, micronutrients, etc. The bacterial seed added should be substrate-specific, in that it should be able to degrade the particular organic substances present in the waste stream. The acclimatisation time could be as low as one week for easily degradable wastes such as sewage/domestic waste, to as high as eight weeks in case of complex wastes.

OPERATIONAL PROCEDURE

A series of steps are involved for the efficient running of the SBR, viz. (1) SBR is filled with freshwater as the diffusers are on, (2) 5-10 percent of the total effluent quantity is added to the contents of the SBR to initially produce a dilute form of the effluent for easy acclimatization of the culture to the wastewater, (3) required quantities of bacterial seed are added to the SBR, (4) the pH and COD of the effluent, coming into the SBR, are checked, (5) the effluent i.e., the supernatant of the SBR at intervals of 8/12 hours, for 2 to 3 days are collected and analysed for the COD levels-the COD reduction pattern over a period of time gives us an indication of the growth or multiplication of the bacteria. Depending upon the COD reduction pattern and the design Mixed Liquor Suspended Solids (MLSS) values and the additional culture requirement with respect to quantity can be worked out, and based on the above pattern of biodegradability, the feed quantity in terms of 5-10 percent at a time can be increased. These procedures are repeated each time for observing the growth rate of the bacterial culture, (6) MLSS and Sludge Volume Index (SVI) values for the contents of the SBR are checked, and confirmed that they are as per the design values. Once the design figures are achieved, the system has achieved a steady-state condition.

Once the above conditions are ensured the plant is ready for taking up the effluent on a continuous basis as per the design parameters (Fig. 1).

PARAMETERS TO JUDGE THE OPERATIONAL

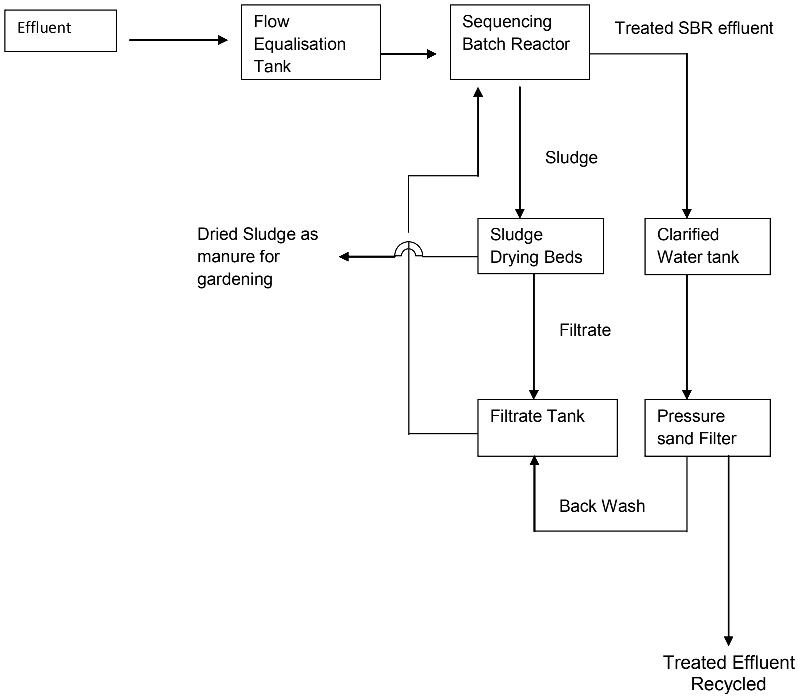


Fig. 1: SBR flow chart.

EFFICIENCY OF THE PLANT PROCESS CONTROL

The effective and efficient operation of the SBR process depends on the maintenance of the steady-state condition. This means that the best operation should be carried out without any sudden changes in any of the variables. This ideal state is, however, would never be present, as the system is always subject to changing conditions that tends to affect and disrupt the steady state. Any sudden change tending to disrupt the process to the point of losing the solid microbial mass (MLSS) and increasing the BOD value in the effluent is termed as 'shocking" the system. However, the plant will be usually designed in such a way as to permit various operator responses to combat shocking conditions. Most of the time, there are several indications of change that warn the operator of impending trouble. Thus, the operator is to be aware of the changing trends from the normal to the abnormal, so that the problem can be correctly identified and the most appropriate action taken.

The important parameters normally used to judge the operational efficiency of a plant are as given below:

Dissolved oxygen: It is the primary criteria for maintaining an aerobic environment in the SBR process. The amount of oxygen transferred into the aeration tank theoretically equals the amount required by the microorganisms to oxidise the organic matter and maintain the residual DO operating levels. The DO level in the aeration tank is further dependent on (1) organic load/strength of the incoming wastewater, (2) the MLSS concentration in the aeration tank, (3) oxygenation capacity of the aeration device (diffusers), (4) the mean cell residence time i.e., retention time of the wastewater in the aeration tank and, (5) the quantity of activated sludge. A decrease in the DO levels result in an increase of the filamentous organisms, causing the phenomenon known as 'sludge bulking', whereas over-aeration (increase in the DO levels) may cause non-filamentous foaming on the surface of the aeration tank. The DO levels should be maintained in the range of 1.5 to 4.0 mg/L in all areas of the aeration tank, with the average value being about 2 mg/L. Dissolved oxygen in the tank helps in detecting anaerobic conditions, excessive turbulence, decrease in the SVI values and filamentous growth. Increase in the DO level is a measure to correct the floating sludge, excess amount of pin-flocs and turbidity in the sewage stream.

Biochemical oxygen demand (BOD): The BOD value of the influent stream helps in assessing the BOD load of the aeration tank. If the desired reduction in the BOD level does not take place due to the excess loading to the aeration tank, it can be rectified by controlling the rate of flow of wastewater by operating the controlling valves. This will result in an increase in the detention time of the effluent in the aeration unit to facilitate better BOD removal.

Microorganisms: A microscopic examination of the wastewater/sewage in the aeration tank reveals various groups of microbes present in the system. A close monitoring of the populations of these various microbial groups help in controlling the process so as to give the best overall performance. A pre-dominance of the filamentous forms (thread-like forms), amoeboids and rotifers indicate an unhealthy, malfunctioning system that gives rise to various operational problems like sludge bulking, reduction in the oxygen levels, floating sludge, pin-flocs, etc. On the other hand, larger populations of free-swimming and attached protozoan called ciliates (floc-formers) are an indication of a healthy, well-operated process. Addition of stoichiometric quantities of chlorine and hydrogen peroxide to the sludge are the methods by which the population of filamentous forms can be reduced. Increasing the sludge age, addition of nutrients like nitrogen and phosphorus, and increasing the rates of air supply are the other corrective measures for reducing filamentous forms.

Sludge wasting: The excess activated sludge produced each day must be wasted to maintain a given F/M ratio or Mean Cell Residence Time (MCRT). This excess sludge is wasted by waste sludge disposal pumps to sludge drying beds. The amount of sludge to be wasted depends on (1) flow rate and strength of the influent stream, (2) MLSS levels in the SBR and, (3) the sludge age.

Oxygen uptake level: Microorganisms in the SBR process use oxygen as they consume the food matter. The rate at which they use oxygen can be taken as a measure of the biological activity. A high oxygen uptake rate (OUR) indicates a high level of bioactivity and vice-versa. The value of OUR is obtained by taking a sample of mixed liquor saturated with DO, and with the help of a DO probe, measuring the decrease in the DO over time. The results are reported as mg of O_2/L min/hr.

Mixed liquor suspended solids (MLSS): The MLSS is the amount of solid particulate matter present in the mixed iquor, i.e., the mixture of activated sludge and raw wastewater. The MLSS is used as an important parameter to design and control the operation of the aeration system. The two factors to be considered in this respect are the MLSS concentration in the aeration tank and the settling ability of the mixed liquor. Maintenance of the MLSS level is very important for optimum treatment of the incoming effluent stream. If the MLSS concentration decreases, the sludge wasting should be decreased to increase the concentration of MLSS in the aeration unit. Conversely, if the MLSS concentration increases, the wasting of sludge is also increased to restore the balance of MLSS in the tank.

Sludge volume index (SVI): Sludge volume index is the ratio of the percent of settled volume of sludge to the percent weight of MLSS.

It is a measure of the settling ability of the activated sludge, and indicates the degree of concentration and the physical state of the sludge. An SVI range of 80-150 indicates proper settling of the sludge, and the healthy operation of the plant. When the SVI is more than 150, it indicates that the sludge settlement is not proper, and at a value of 200, the problem of sludge bulking begins. The methods of control of SVI values are by controlling the MLSS concentration and flow of effluent in the aeration tank. An SVI value above 150 means the amount of sludge wasted has to be increased, and the quantity of return active sludge from the settling tank should be reduced.

pH range: The pH in the aeration tank should be maintained at a near-neutral value for the proper operation of the plant. An effluent having neutral pH has many advantages viz., (1) a neutral pH provides the conditions for the best metabolic activity and the ability to withstand shock loading, (2) oxygen uptake is optimum at a pH range of 7.0-7.4 and, (3) the

Table 1: The chemical analysis of raw and treated effluents.

Raw Effluent					Treated Effluent					% COD	% BOD
pH	TSS	TDS	COD	BOD	pH	TSS	TDS	COD	BOD	Removal	Removal
7.9	70	1350	2883	1450	7.6	14	1210	81	10	97.19	99.31
8.3	40	1200	4120	2200	8.2	12	1120	260	16	93.69	99.27
8.4	50	1300	2277	1050	7.9	16	1270	99	12	95.65	98.86
8.4	100	1200	2540	1089	7.7	14	1150	70	20	97.24	98.16
8.5	50	1540	4840	2540	7.9	14	1450	270	20	94.42	99.21
8.4	35	1300	4851	2400	8.0	16	1200	297	22	93.88	99.08
8.4	60	1560	4752	2420	7.8	12	1494	317	26	93.33	98.93
7.9	40	1350	2121	2026	7.8	10	1260	424	28	80.01	98.62
8.1	55	1150	1713	1250	7.6	16	1125	179	26	89.55	97.92
7.1	70	1200	4732	1400	7.0	12	1100	277	20	94.15	98.57
7.7	58	1682	6894	3356	7.6	14	1496	204	26	97.04	99.23
8.1	54	1560	4920	2450	7.8	16	1462	164	16	96.67	99.35

All parameters are in mg/L except pH.

BOD removal efficiency decreases as the pH moves away from this range. If the changes in the pH values are gradual, there will not normally be any serious damage to the process. However, the sudden changes in the pH values, such as occurring due to addition of certain type of industrial wastes (highly acidic or alkaline) are the most dangerous, and can result in killing some or all of the micro-organism population. It is for this reason that the pH should be continuously monitored at the inlet point of the plant. If it is detected at this point, the operator may be able to utilise the detention time in the equalisation tank to neutralise the effluent.

Toxic loading: Toxic loads are defined as those elements or compounds, which enter the treatment plant in sufficient concentration to kill the resident population of microorganisms, and cause temporary system collapse. The typical examples of such toxic loads are the discharge of cyanides and heavy metals such as chromium from metal processing industries. Proper methods for handling the toxic loads involve (1) dilution of the waste and holding all the sludge possible in the aerator, i.e., the MLSS concentration is maintained at a high level to provide a cushion against the toxins, (2) contain the waste in some spare tank and then gradually bleed it through the process and, (3) the toxic waste should be diverted through various bypass arrangements.

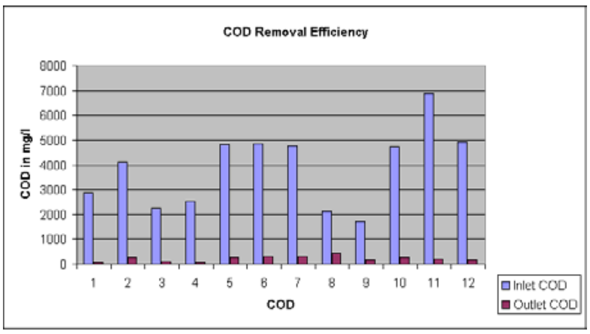
Temperature range: An optimum temperature range of 15-40 degrees C is essential for the proper functioning of the system. This is because majority of the microbes are mesophilic and function only in the moderate temperature range of 15-40 degrees C. The temperature changes above or below this optimum range results in (1) decrease in the metabolic activity of the organisms due to decrease in temperature which ultimately reduces the performance efficiency of the system, (2) a thinner sludge can also be expected due to the temperature drop in the colder months, (3) the slower reaction rates observed at colder temperatures will result in a slower response rate in the case of system upsets and, (3) an increase in temperature above the mesophilic range can result in killing of some or entire microbial population of the system.

Process operational problems: The three most common problems encountered in the operation of an activated sludge process are (1) bulking sludge, (2) rising sludge, and (3) foaming.

Bulking sludge: The bulking sludge is one that has poor settling characteristics and poor compactability (Rao & Datta et al. 1987). Two main types of sludge-bulking problems have been identified. One is caused by the growth of filamentous organisms (filamentous bulking), while the other is due to the condition known as 'bound water' in which the bacterial cells comprising the 'floc' swell by the absorption of water (non-filamentous bulking). This reduces the density of the floc causing it to float on the surface of the tank. Filamentous bulking is caused by low DO levels in the aeration tank, insufficient amount of micronutrients like urea, DAP, etc., widely varying organic loading (wastes of varying strength), and low F/M ratio. Over-aeration of the tank contents and presence of certain toxic compounds in the waste stream also cause non-filamentous bulking.

Bulking can be controlled by monitoring the optimum DO level in the aeration tank by adding regular dosages of sufficient quantities of micronutrients, preventing wide fluctuations in pH and organic loading, and maintaining optimum range of F/M ratios.

Rising sludge: Occasionally, sludge that has good settling characteristics is seen to rise to the surface after a relatively short settling period. The cause of this phenomenon is usually denitrification in which case the nitrates and nitrites in the wastewater are converted into nitrogen gas. As the gas is formed, it gets trapped in the sludge mass and makes it rise to the surface. Rising sludge can be differentiated from bulking sludge by the presence of small gas bubbles attached to the floating solid particles. This can be overcome by (1) increasing the rate of sludge wasting from the settling tank to



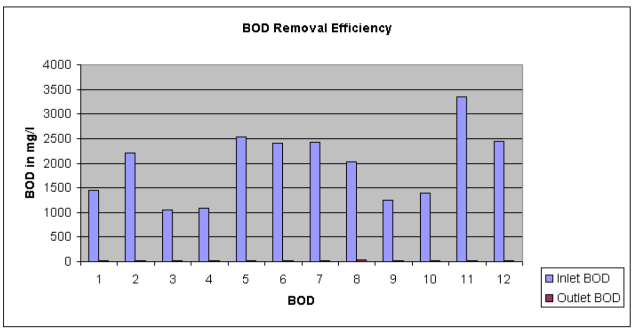


Fig. 2: Efficiency of COD and BOD removal.

reduce its detention time which prevents denitrification, (2) decreasing the rate of flow from the aeration tank to the settling tank, and (3) preventing nitrites and nitrates in effluent.

Odour: A healthy, well-monitored plant can be operated with the minimum amount of odour. However, odours occasionally develop from the sources like septic wastewater, wastes from certain specific industrial processes, accumulated screenings and grit, sludge thickening/digestion tanks and sludge drying beds, etc. This problem can be overcome by (1) maintaining aerobic conditions by increasing the rate of aeration and mixing, (2) controlling anaerobic microbial growth by periodic disinfection or pH control, (3) preventing excessive turbulence in the aeration tank, and (4) increasing the frequency of sludge and scum wasting.

RESULTS AND CONCLUSION

The results of the analysis of the raw and treated effluents are given in Table 1. The COD and BOD results have been plotted graphically in Fig. 2. From the analysis it can be seen that the removal efficiency of COD and BOD is 93.34% and 98.98% respectively.

The Bio-sludge generated is non-toxic and can be used as a manure for horticulture. Wastewater treatment has been a challenge throughout the world due to varying influent chemical and physical characteristics and stringent effluent regulations. Treatment systems using activated sludge have been able to handle many of these difficulties. The availability of artificial intelligence has now made the option of a SBR process more attractive, thus, providing better controls that results in good wastewater treatment. The distinct advantages of SBR methods are (1) high quality effluent consistency that can be achieved at widely varying loads, (2) no primary or secondary clarifiers are required and require less maintenance, (3) decreased capital and operation and maintenance costs due to no sludge recycling, (4) improved settling provided under perfect quiescent conditions, (5) reduced labour costs through automated controls, (6) power savings due to lower oxygen requirements, (7) decanter eliminates infiltration of solids into the effluent, (8) acclimated biomass stabilization is possible under shock BOD loads and large flow variations, and (8) small space requirements. Thus, these advantages of SBR process make it an efficient alternative in industrial wastewater treatment.

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