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A Review of an Integrated Anaerobic-Aerobic Systems for the Treatment of Food Processing Wastewater

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.*Abstract*: ***Food processing industry is believed to be one of the most polluting industry as it produces highly polluted wastewater in term of organic and suspended matter. Previously, such wastewater has been treated by anaerobic and aerobic treatment. At present, the effluent standards become such stringent that it is not possible to achieve it by using conventional anaerobic and aerobic treatment. Solution of this problem is to utilize integrated treatment consisting of both aerobic and anaerobic treatment. This paper provides the review of the currently available integrated treatment used in food processing wastewater treatment. Integrated bioreactor is classified into two types based on configuration, which are (1) Integration bioreactor with physical separation of aerobic and anaerobic zone and (2) Integration bioreactor without physical separation of aerobic and anaerobic zone. The integration of anaerobic and aerobic process enhances the overall degradation efficiency. The advantageous of various integrated bioreactor are highlighted and compared. The comparison of various bioreactor shows that the use of integrated bioreactor without physical separation is advantageous over other bioreactor as it requires less space, less capital cost and higher COD removal.***
Key words – Food processing industry, Aerobic-Anaerobic process, Integrated bioreactor.

1. Introduction

Water is one of the substances available in abundant quantity in nature which men have exploiting more than any other natural resources for existence. Water is considered as ELIXIR OF LIFE. Water is required for various beneficial purpose i.e. drinking, sanitation, irrigation, power generation, industrial purpose etc. About earth's 73 % surface is covered with water. From the earth's total water resource, 97 % is saline water stored in ocean that couldn't be used directly for beneficial purposes and 3 % is fresh water. From the total fresh water resource, 68.7 % is in glaciers, 30.1 % is as ground water and 0.9 % other. Therefore only 0.3 % of earth's total water resource is available for drinking purpose [1]. At present, water scarcity is worldwide problem due over use and pollution of natural water source. The main cause of water pollution is industrialization. Industries pollute the natural water body by discharging their wastewater generated during the course of their different activities. The quantity and quality of wastewater generated depends on type of industry. i.e. food industry, petroleum refinery, cement industry, textile industry etc.

Food processing includes the methods and techniques used to transform raw ingredients into food for human consumption. Major industries constituting the food processing sector are grain milling, sugar, edible oils, beverages, fruits & vegetables processing and dairy products. The Indian food industry is poised for huge growth, increasing its contribution to world food trade every year. In India, the food sector has emerged as a high-growth and high-profit sector due to its immense potential for value addition, particularly within the food processing industry [2] [3]. Mechanical life style and crave for comfort is pushing people towards ready to eat services. Though it is very good for the progress of the industry, it also leads to the generation and consumption of water in tremendous volumes. Traditionally, the food-processing industry has been a large water user. Water is used as an ingredient, an initial and intermediate cleaning source, an efficient transportation conveyor of raw materials, and the principal agent used in sanitizing plant machinery and areas [4]. Wastewater generated from these industries depicts wide variation in strength and characteristics but this wastewater is nontoxic in nature because it comprises less hazardous compounds. Almost 50% of the water utilized in food processing industry is for washing and rinsing purposes.

FPI generate large volume of wastewater which either join the stream or other water bodies or affects the water quality. Wastewater stream discharged from FPI have high organic and nutrient content therefore if discharged without proper treatment, it tends to cause serious water pollution. If wastewater from FPI is allowed to discharge into stream, it will add the sludge forming material and product in suspension which upsets the dissolved oxygen balance of water and releases obnoxious gases to the atmosphere. If the quantity of all forms of organic material is high w.r.t. to the volume of the receiving water, the bio-chemical reaction tends to deplete oxygen in the stream. As a result, anaerobic conditions are created which produce odor. During summer, gaseous products may lift up the sludge to the surface creating unsightly and odorous conditions.

This wastewater has been reported to be treated by aerobic and anaerobic biological techniques. In general, aerobic processes are suitable for the treatment of low strength wastewater(COD<1000 mg/L) while anaerobic processes are suitable for the treatment of high strength wastewater(COD in range of 4000 mg/L) [5]. The comparison of both the treatment is given in Table 1 [5]. Anaerobic treatment is advantageous over aerobic treatment when treating influents in higher concentrations of organic matter, and generally it requires less energy with potential for bioenergy and nutrient recovery. As compared to anaerobic processes, aerobic processes achieve higher removal of soluble biodegradable organic matter material and the produced biomass is generally well flocculated, resulting in high quality effluent.

Table 1 Comparison of aerobic and anaerobic process

Feature	Aerobic	Anaerobic
Removal efficiency	High	High
OLR	Moderate	High
Effluent quality	Excellent	Moderate to poor

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Sludge Production	High	Low
Start up	2 – 4 week	2 – 4 month
Odor	Less potential for odor	Potential odor problem
Nutrient requirement	High	Low
Energy requirement	High	Low to moderate

Though the anaerobic treatments are desirable to treat high strength industrial wastewaters due to the high level of COD, potential for energy generation and lower sludge production, it suffers from the low growth rate of the microorganisms, a low settling rate, process instabilities and the need for post treatment of the noxious anaerobic effluent which often contains ammonium ion ($NH4+$)and hydrogen sulfide ($HS-$) [5]. In most applications, however the efficiency of the anaerobic process is high, complete stabilization of the organic matter is impossible by the anaerobic treatment due to the high organic strength of the wastewater. Because of the final treated effluent from anaerobic treatment contains soluble organic matter, subsequent post treatment using aerobic treatment is required to meet the effluent discharge standard. Thus, it indicates the potential for anaerobic–aerobic systems to treat the high strength industrial wastewater. Benefits of anaerobic – aerobic process are listed below [5][6]:

ϴ Resource recovery: Anaerobic pretreatment removes most of the organic pollutants and converts them into a useful fuel, biogas.

ϴ High overall treatment efficiency: Aerobic post-treatment polishes the anaerobic effluent and results in very high overall treatment efficiency.

ϴ Less disposal of sludge: By digesting excess aerobic sludge in the anaerobic tank, a minimum stabilized total sludge is produced which leads to a reduction in sludge disposal cost. As an additional benefit, a higher gas yield is achieved.

ϴ Lower energy consumption: anaerobic pretreatment acts as an influent equalization tank, reducing diurnal variations of the oxygen demand and resulting in a further reduction of the required maximum aeration capacity.

ϴ Less volatilization in aerobic treatment: volatile compound is degraded in the anaerobic treatment, removing the possibility of volatilization in the aerobic treatment.

2. Type of anaerobic-aerobic treatment systems

Figure 1 shows the main types of anaerobic –aerobic systems based of the different approaches used to obtain an integrated system.

The conventional anaerobic-aerobic treatment includes aerated stabilization ponds, aerated and non-aerated lagoons, and natural or artificial wetland systems. Aerobic treatment occurs in the upper part (euphotic zone) of these systems while anaerobic treatment occurs at the bottom part (benthic zone). Conventional anaerobic–aerobic systems usually comprise of large ponds connected in series having long hydraulic retention time (HRT), low organic loading rate (OLR). Thus, the conventional treatment systems suffer from problems of large space requirement, noxious gas emissions from large open system, lower treatment efficiencies, huge excess sludge production.

To overcome this the drawbacks of conventional anaerobic–aerobic systems, the new technologies have been developed over the years. Anaerobic–aerobic system that utilize high rate bioreactors provide treatment which is techno-economically viable with simultaneous resource recovery and compliance with effluent discharge standards. With the more technological advancement, more intensive form of biodegradation can also be achieved by integrating anaerobic and aerobic zones within a single bioreactor. Essentially, this integrated anaerobic–aerobic bioreactor classified into two types: (i) integrated bioreactors with physical separation of anaerobic–aerobic zone, (ii) integrated bioreactors without physical separation of anaerobic–aerobic zone.

3. Type of anaerobic-aerobic integrated reactors

The integrated bioreactors are possible alternative for FPI wastewater treatment to meet stringent norms with respect to space, odor and biosolids production. Though, the integrated bioreactors are cost effective, efficient and having smaller foot prints compared to other types of anaerobic–aerobic systems, the design, operation and process development of integrated anaerobic–aerobic bioreactors are limited to a few studies.

3.1 Integrated bio reactors with physical separation of anaerobic and aerobic zones

As shown in Table 2, Some approaches have been attempted to obtain the integrated bioreactors by combining anaerobic and aerobic processes in separate zones.

3.1.1 Anaerobic – aerobic baffled bioreactor

An anaerobic–aerobic baffled bioreactor was proposed for the treatment of potato starch processing wastewaters with COD values ranged from 1100 to 4500 mg/L [7]. In aerobic zone, to increase the efficiency, porous burnt-coke particles added as carrier media to support growth of microorganisms. The carriers provide huge surface area for the attachment of the biofilm which in turn leads to an increased biomass concentration responsible for degradation of organic matter. The COD reduction efficiency in presence of burnt coke media and in absence of burnt coke media is 98.7% and 96 %, respectively. An optimal HRT ranged from 12 to 24 h was used.

As shown in figure 2, anaerobic–aerobic baffled consists of three anaerobic zones, two settling zone and one aerobic zone. It is rectangular with equally divided down flow and upflow sections by 5-mm thick vertical high/low baffles. The baffles cause the wastewater to rise and then flow downwards into the reactor due to the 45◦ turn out angle. The anaerobic zone is subdivided into three zones. The first and second anaerobic zones are designed for hydrolysis, while the third anaerobic zone is designed for methanogenesis. Settling zone are designed for sedimentation and having main function to maintain anaerobic condition into anaerobic zone by separating it from aerobic zone.

The advantages of this bioreactor include rapid biodegradation, lower excess sludge production and excellent process stability. Thus, this may be effective solution to the treatment of wastewater from SMEs which has small economic capacity to invest in environmental controls.

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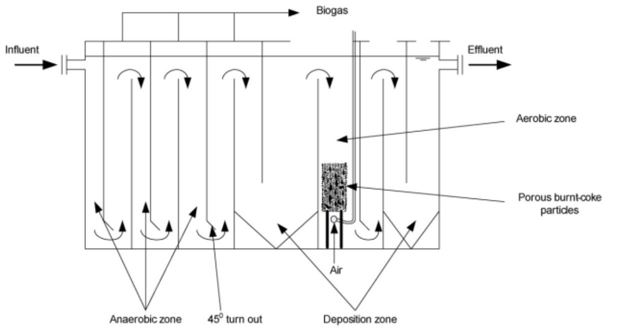

Figure 2 Anaerobic-aerobic baffled bioreactor [5]

3.1.2 Simultaneous aerobic – anaerobic(SAA) bioreactor

As shown in figure 3 , the simultaneous aerobic–anaerobic (SAA) bioreactor combines air lift reactor, fluidized bed and upflow anaerobic sludge blanket [5] [8]. It mainly consists an inner and an outer cylinder. The aerobic and anaerobic zones are created by controlling aeration location, aeration capacity and reactor shape. The aerobic zone is formed in the inner cylinder by providing air from the bottom of the bioreactor. The anaerobic zone is formed in the outer cylinder due to limited oxygen transfer from the aerobic central zone. The influent enters into the SAA from bottom and effluent leaves from the top of the SAA. As we move from top to bottom, there is a decrease in dissolved oxygen concentration due to the reactor configuration which enables the water flows from the inner zone to the outer zone. Under oxygen-limited condition, aerobic and anaerobic process occurs simultaneously as a result of dissolved oxygen concentration gradients arising from diffusion limitations [5] [9].

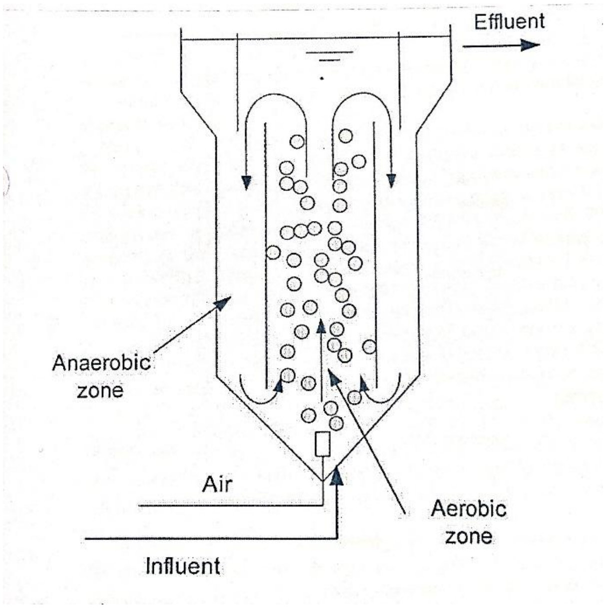

Figure 3 schematic diagram of SAA reactor [5]

This SSA is proposed for the treatment of landfill leachate having COD 1000 to 3300 mg/L. The average COD reduction efficiency of SSA was 94 %.

The SAA bioreactor system is advantageous over the conventional biological process for removal efficiency of organic and nitrogenous matter from landfill leachates due to the reduced space requirement and operation management. Energy consumed mainly in pumping the influent and air compressor for air supply. Due to the simplicity, SAA bioreactor system is a good alternative for FPI wastewater treatment.

3.1.3 Bubble column with draught tube

As shown in figure 4 , a cylindrical bubble column with a draught tube used as a small treatment unit of anaerobic–aerobic process and nitrogen removal is observed for performance evaluation [10].

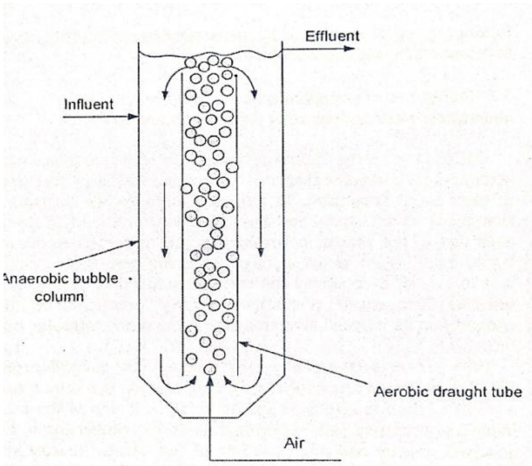

Figure 4 Bubble column with draught tube [5]

The inside and outside of a draught tube are acted as an aerobic zone and an anaerobic zone, respectively. The wastewater is initially introduced to the upper part in outer side (anaerobic zone) and then flows through draught tube (aerobic zone) by the air-lift action. Finally, the treated effluent is withdrawn from the top of the draught tube. The volume ratio of anaerobic to aerobic zones in the bubble column can be adjusted by changing the diameter of the draught tube. The circulation of mixed liquor between the anaerobic and aerobic zones is the most important operating parameter. It can be adjusted by changing the height of the draught tube and the air flowrate. The increase in the circulation rate will cause aerobic conditions to persist in outside of draught tube which is meant to be anaerobic. Therefore, the bubble-column treatment unit should be operated at such circulation rate that can keep the sludge in suspending state.

The main advantage of the bubble column is no requirement for additional equipment to circulate the mixed liquor between aerobic and anaerobic zone. Furthermore, this type of bioreactor can be used for small scale FPI. Notwithstanding, the residence time in each zone is short during the circulation as compared to other anaerobic–aerobic processes. So as to keep the sludge in a suspension, a minimum circulation flow rate is required which is in contrast to longer residence time.

3.2 Integrated bio reactors without physical separation of anaerobic and aerobic zones

A number of integrated bioreactors have been developed which allow the coexistence of anaerobic and aerobic microorganisms inside the same reactor are listed in Table 2. These bioreactors do not have any physical means to separate anaerobic and aerobic zone. It has mainly stacked configurations with lower part as an anaerobic and upper part as an aerobic zone. This is achieved by supplying air at an intermediate height of the reactor.

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3.2.1 Upflow anaerobic/aerobic fixed bed (UA/AFB) integrated reactor

Figure 5 shows a bench scale up flow anaerobic/aerobic fixed bed integrated bioreactor and it was tested with synthetic wastewater [11]. It is filled PVC media having 1.5 cm diameter. It consists of lower anaerobic zone and upper aerobic zone. The influent is pumped from bottom (anaerobic zone) and treated effluent is withdrawn from top (aerobic zone). It has been provided with total HRT of 9 h (5 h for anaerobic zone and 4 h for aerobic zone) which is sufficient to achieve efficient COD removal up to 95% at OLR as high as 7.4 kg COD/m3 day.

This bioreactor is capable of handling high organic loads. It is a potential biotechnology for treatment of industrial wastewater containing high organic loads (such as FPI wastewater). The proposed study did not incorporate a methane collection system, which would collect biogas to make up for cost of treatment.

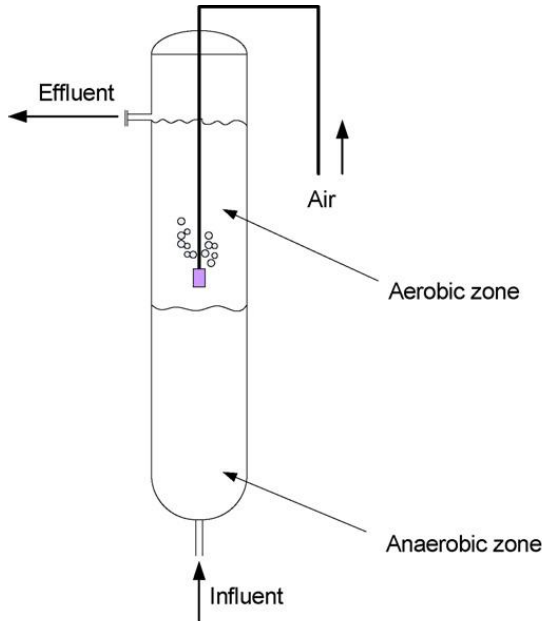

Figure 5 Schematic diagram of Upflow anaerobic/aerobic fixed bed (UA/AFB) integrated reactor [5]

3.2.2 Staged anaerobic – aerobic membrane bioreactor

As shown in figure 4, a staged anaerobic–aerobic membrane bioreactor (MBR) includes membrane module, diffuser and porcelain carriers [11]. The membrane module is submerged in the aerobic zone and aerated with diffuser which serves oxygen for the biodegradation of substrates, mixing of the aerobic tank and producing desirable turbulence for membrane cleaning. Porcelain carriers are added with view to prevent the blockage of the orifice between an anaerobic and an aerobic zone.

Synthetic wastewater, COD up to 10,500 mg/L and NH4+-N up to 1220 mg/L, has been employed for the study [11]. The aerobic zone is provided with an intermittent aeration which promotes the simultaneous nitrification and denitrification. The observed COD removals were exceeding 99% for OLR up to 10.08 kg COD/m3 day. Between 60 and 80% of COD was anaerobically biodegraded in the anaerobic zone and converted to methane which in turn could serve as a carbon source for the denitrification in the aerobic zone.

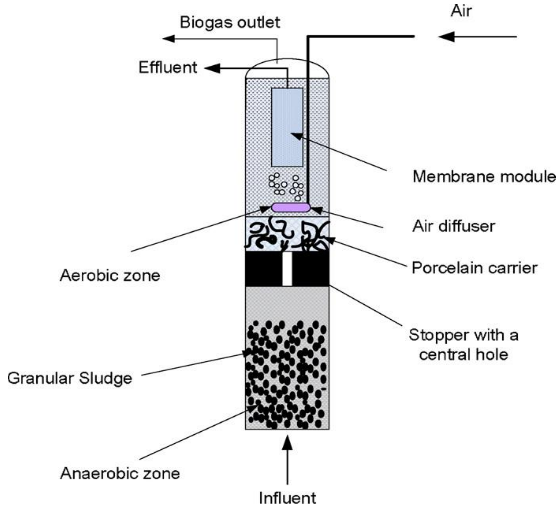

Figure 6 schematic diagram of anaerobic-aerobic MBR [5]

3.2.3 Integrated anaerobic – aerobic fixed film reactor

An integrated anaerobic–aerobic fixed-film reactor (FFR) exhibited high performance on the removal of organic matter from slaughterhouse wastewater [13]. Overall COD removal efficiencies of 93% were achieved for an average OLR of 0.77 kg COD/m3 day at HRT of 0.94–3.8 days. It is to be reported that the integrated anaerobic–aerobic FFR achieves higher treatment efficiency than the anaerobic–aerobic FFB system having separate anaerobic and aerobic reactor.

As shown in figure, anaerobic–aerobic FFR consists of vertically configured corrugated tubes. The reactor is divided without any physical means into two compartments. Air was supplied by membrane diffuser into aerobic zone. Wastewater enters into the upper part of the non-aerated anaerobic region through which it circulates downwards then it is entrained up through the aerated zone due to the air-lift effect of the air injection. Then it leaves the reactor from the upper part of the aerobic zone. Different anaerobic–aerobic volume ratios are achieved by turningon and off each diffuser at the bottom.

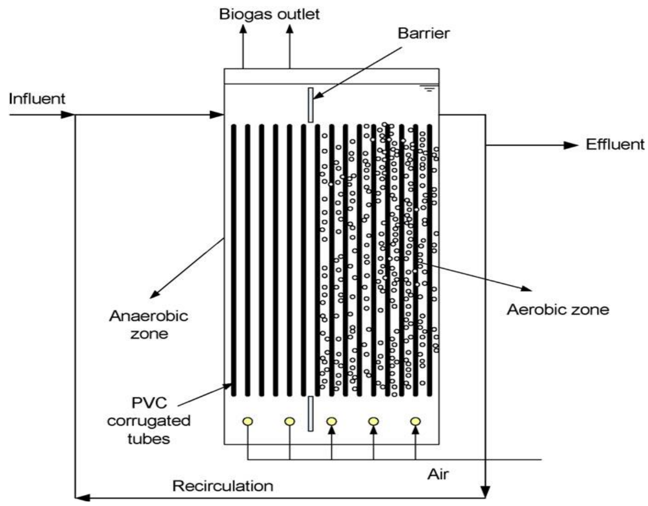

Figure 7 schematic diagram of integrated anaerobic-aerobic FFB [5]

Most of the COD was removed through aerobic oxidation rather than the anaerobic oxidation due to lower extension of anaerobic process resulting from high mixing pattern. High recirculation makes homogeneous aerated and non-aerated region and maintains the DO 1.4mg/l in the non-aerated zone.

This limits the methanogenic processes. Similar phenomenon was also reported by other authors working with bubble columns [10]. Thus, it is needed to clearly separate the aerated and non-aerated zones that maintain strict anaerobic conditions. That's why, the two small barriers are provided at the top and at the bottom of the reactor. The aerated and non-aerated region are set up in parallel configuration to recover methane.

3.2.4 Integrated anaerobic – aerobic fluidized bed reactor

The proposed pilot scale study was carried out by anaerobic–aerobic fluidized bed reactor for the simultaneous elimination of organic carbon and nitrogen from municipal wastewater [13]. The COD removal efficiency higher than 80% were obtained at HRT of 24 h for an OLR of 1.2 kg COD/m3 d.

As shows in figure 8, the integrated anaerobic–aerobic fluidized bed reactor mainly consist of cylindrical fluidized bed with pulverized pumice-stone as support material and the aeration is carried out by four fine bubble cylindrical membrane diffusers. This system is supported by a 'bell' (at the top) and different anaerobic zone to aerobic zone volume ratios can be accomplished by adjusting the height of bell.

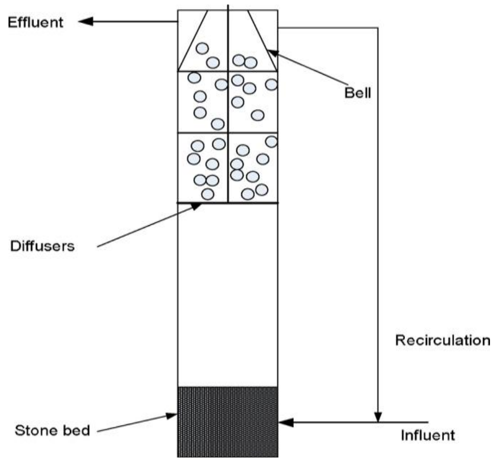

Figure 8 Integrated anaerobic-aerobic fluidized bed reactor [5]

The bioreactor remained stable under varying organic load. It has a short start-up time and ability to absorb shock loads. The energy mainly consumed in pumping to maintain the support media in suspension.

4. Merits and Demerits of Integrated bioreactor

Anaerobic-aerobic integrated bioreactors have shown significant treatment efficiency in terms of COD removal as compared to other biological systems. They are also capable of handling high OLR when compared to conventional anaerobic as well as aerobic process. Nonetheless, the design and configuration of integrated bioreactor are more complex so construction cost unsurprisingly would be higher than other types of bioreactor. The anaerobic-aerobic system with suitable methane collection facility arises as a sustainable technology for treatment of high strength FPI wastewaters with simultaneously energy recovery source.

5. Conclusion

Development of the integrated anaerobic–aerobic bioreactors resolves many problems related to space, odors and excessive sludge production. It is ideated that the integrated bioreactors will be able to treat a wide range of high organic strength FPI wastewater with generation of renewable energy and higher treatment efficiency. However, most of the integrated bioreactors discussed in this review not yet implemented on large scale within FPI so further work is required to lack large scale implementation within industry and further study is required to evaluate the performance of these integrated bioreactors on a larger scale.

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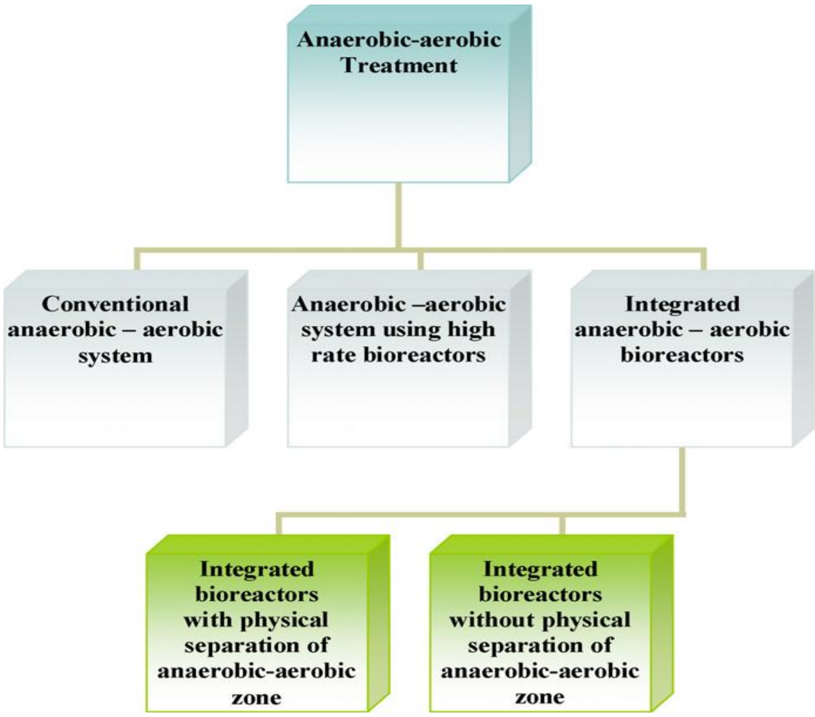

Figure 1 Types Of Anaerobic-Aerobic Systems [5]

Table 2 Integrated Rectors with Physically Separated Anaerobic-Aerobic Zone

Reactor	Wastewater	Influent COD (mg/L)	Total COD removal (%)
Anaerobic-aerobic baffled reactor	Potato starch wastewater	1100 – 4500	88.4 – 96.7 %
SAA reactor	Diluted landfill leachate	1000 – 3300	94 %
Bubble column with draught tube	Synthetic wastewater	-	-

Table 3 Integrated Reactors without Physically Separated Anaerobic-Aerobic Zone

Reactor	Wastewater	Influent COD(mg/L)	Total COD removal (%)
Upflow anaerobic/aerobic fixed bed integrated reactor	Synthetic wastewater	365 – 3500	95 – 98 %
Staged anaerobic-aerobic membrane bioreactor	Synthetic wastewater	1300 – 10500	> 99 %
Integrated anaerobic-aerobic fixed film reactor	Slaughter house wastewater	1190 - 2800	93 %
Integrated anaerobic-aerobic fluidized bed reactor	Municipal wastewater	350	> 80 %