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Review Article

# REVIEW OF RESEARCH ON BIO REACTORS USED IN WASTEWATER TREATMENT FOR PRODUCTION OF BIO HYDROGEN: FUTURE FUEL

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## ABSTRACT

The review presented in this paper focuses on reactors used in wastewater treatment for bio hydrogen production (e.g. batch reactors, complete mix reactors, plug flow reactors, bio-film reactors, suspended reactors, upflow anaerobic sludge blanket reactor, anaerobic baffled reactors, upflow packed-bed attached growth reactors, attached growth fluidized bed reactors, anaerobic sequencing batch reactor, hybrid / high rate reactors and membrane separation reactors. It is clear from the review that development of these reactors can be considered a grown up research for which good design and scale-up guidelines are available.

**Keywords:** Bio Hydrogen ,Wastewater treatment, Reactors, Anaerobic process.

# INTRODUCTION

Hydrogen is an ideal, clean and sustainable energy source for the future because of its high conversion and non-polluting nature.The interest in hydrogen resurfaced in the 1990's [1-3] when it became apparent that the atmospheric pollution by fossil fuels was considered not only unhealthy but also as a major cause for global climatic changes. At the moment, the US Department of energy, Washington DC, is currently spending about 1 million $ per year in Biohydrogen research while Japan is spending five times as much in that area. These sums are far below to what both the long-term promises and near-term opportunities of their practical applications can ensure. Given the economic uncertainties and environmental hazards of fossil fuels, working out the technical and economic feasibility of hydrogen has gained major importance as we entered the 21$^{st}$ century [4].

The production of hydrogen from wastewaters creates new challenges because the waste materials are not sterile and it would be too costly to sterilize them and maintain aseptic conditions. In addition, wastewaters usually are composed of a variety of substrates that can be most efficiently used by different species of bacteria. Thus, hydrogen production from complex organics in wastewaters will require that different bacteria grow under mixed culture conditions. Unfortunately, some of the bacteria present in the microbial inoculum or wastewater will consume hydrogen, lowering the overall efficiency of hydrogen production.To try to increase the efficiency of hydrogen production in bioreactors using complex wastewaters, we examined in this study the availability of different types of bio reactors for hydrogen production.

## Batch Reactors:

In a batch reactor, flow is neither entering nor leaving the reactor (i.e., flow enters, is treated, and then is discharged, and the cycle repeats). The liquid contents of the reactor are mixed completely. Batch reactors are often used to blend chemicals or to dilute concentrated chemicals [5].

## Complete mix Reactors:

In this reactor, it is assumed that complete mixing occurs instantaneously and uniformly throughout the reactor as fluid particles enter the reactor. Fluid particles leave the reactor in proportion to their statistical population. Complete mixing can be accomplished in round or square reactors if contents of the reactor are uniformly and continuously redistributed. The actual time required to achieve completely mixed conditions will depend on the reactor geometry and power input[6].

## Plug flow Reactors:

Fluid particles pass through the reactor with little or no longitudinal mixing and exit from the reactor in the same sequence in which they entered. Their identity remains in the reactor for a time equal to the theoretical detention time. This type of flow is approximate in long open tanks with a high length to width ratio in which the longitudinal dispersion is minimal or absent[5]. Operational factors that must be considered in selection of type or reactor to be used in the treatment process includes:

- Nature of wastewater to be treated
- Nature of reaction (homogeneous/heterogeneous)
- Reaction kinetics governing the treatment process
- Process performance requirements
- Local environmental conditions.

## Bio-film Reactors:

An inert medium or biomass carrier is added to treatment vessel and process is operated to favor the growth of microorganisms on medium surface. This physical attachment prevents biomass washout and leads to high values of elevated reactor microorganism concentration and solids retention time. It also permits these reactors to be operated with the liquid upflow velocities that would easily washout the nonattached biomass. To obtain full benefits of fixed film reactor systems, Internal reactor mass transfer deficiencies must be avoided.

In fixed bed reactors, a large proportion of retained biomass is not attached to packing medium. This nonattached material is retained in the interstices between media particles partly through influence of physical contact with the media. Because the nonattached biomass contributes significantly to treatment activity in an upflow fixed bed system, relatively low upflow velocities are usually maintained to prevent washout of this material.

Excessive levels of nonattached biosolids can be identified by direct sampling through reactor sampling ports, by presence of higher levels of suspended solids in reactor effluent, or by deterioration in RTD characteristics of the reactor. At this point, solids must be removed from the packing by draining and backwashing the media [7].

## Suspended Reactors:

The simplest suspended growth reactor is the batch reactor. The reactor is filled with appropriate proportions of liquid or slurry streams to be treated, the bacterial culture to be used, and the required nutrients, such as nitrogen and Phosphorus. Then, the reactor contents are stirred if needed to keep reactor contents in suspension, and air/$O_2$ is introduced if process is aerobic. The biochemical reactions then take place without new additions until reaction is complete. Some or all of the contents are then removed and new liquid or slurry stream and culture, etc are added if cycle is to be repeated. Batch reactors commonly are used in lab-scale basic investigations and treatability studies because of their ease of operation and the absence of mechanical pumps, which can be costly and difficult to maintain. Batch reactors are finding increasing use for treatment of soil slurries in which it is difficult to degrade the contaminants that are present. The kinetics of contaminant removal in batch reactor is similar to that of an ideal plug flow reactor, a system that can lead to highly efficient removal of an individual contaminant. This recognition has led to the concept of sequencing batch rectors, a treatment system that employs several batch reactors operated in parallel. One can be filling, one can be emptying, and one or more can be treating. Thus, flow to system of reactors can be continuous, even though the treatment is batch. Indeed, with such batch operation, a single reactor may be operated aerobically for a part of the time, such as to obtain ammonia nitrification, and subsequently operated under anoxic conditions, such as to obtain denitrification [8].

## Industrial Anaerobic Wastewater Treatment Reactors:

A number of reactors have been developed for optimized working of Industrial scale anaerobic fermentation reactions. Some of the most important reactors are:

## Upflow Anaerobic Sludge Blanket Reactor:

One of the most notable developments in anaerobic treatment process technology was the upflow anaerobic sludge blanket (UASB) reactor in the late 1970's in Netherlands by Lettinga and his coworkers [9-10]. Critical elements of the UASB reactor design are the influent distribution system, the gas-solids separator, and the effluent-withdrawal design. Modifications to the basic UASB design include addition of a settling tank and use of packing material to the top of reactor. Both modifications aimed at better solids capture and prevention of loss of solids, which upsets sludge characteristics and density. The key feature of the UASB process that allows the use of high volumetric COD loadings compared to other anaerobic processes is the development of a dense granulated sludge. The development of the sludge is affected by the wastewater characteristics. The presence of other suspended solids in the sludge blanket can also inhibit the density and formation of granulated sludge.

## Anaerobic Suspended Film Contact Systems:

The basis for anaerobic suspended film contact reactor (ASCR) design is to ensure effective contact with the anaerobic biomass in suspended form with organic load to achieve high organic load removal. To achieve this the inlet feed was introduced through the bottom of the reactor by which the settled sludge will be in continuous motion in the reactor. This enables organic substrate to have good contact with the suspended film of the active biomass to ensure effective degradation. Also, the feed introduced in the bottom of the reactor will pass through the reactor from bottom in a phased manner for period of the hydraulic retention time of 6 to 12 hours. A degasities is usually needed to minimize floating solids in the separation step. In this reactor, it was confirmed that the increase in organic loading rate from 2 to 10 g of COD/day increased the COD removal rate and the subsequent increase from 10 to 20 g of COD/day decreased the COD utilization rate from 80% to 30% [11-12].

## Anaerobic Baffled Reactor:

In the anaerobic baffled reactor, baffles are used to direct the flow of wastewater in an upflow mode through a series of sludge blanket reactors. The sludge in the reactor rises and falls with the gas production and flow, but moves through the reactor at a slow rate. Performance improvement included various modifications like (1) Changes to baffle design; (2) hybrid reactors with a settler used to capture and return the solids; and (3) packing in upper part of each chamber for solid capture. [13] Its advantages included Simplicity in operation, long solids retention times, non-requirement of specially activated biomass, use on a wide variety of wastewaters, kinetics improvement for sludge operation and stability to shock loads. The main limitations with the ABR process is the lack of information based on operation of full-scale facilities and a full understanding of system hydraulics.

## Upflow Packed-Bed Attached Growth Reactor:

Full-scale up flow packed bed anaerobic filters are used in cylindrical or rectangular tanks at widths and diameters ranging from 2 to 8 m and heights from 3 to 13 m. The most common packing materials are corrugated plastic cross-flow or tubular modules. A large portion of the biomass responsible for treatment in the upflow attached growth anaerobic processes is loosely held in the packing void spaces and not just attached to the packing material [14]. Low upflow velocities (of the range of 0.6 to 0.9 m/h) are generally used to prevent washing out the biomass. Over time, the solids and biomass will accumulate in the packing to cause plugging and flow short-circuiting. At this point, flushing and draining the packing must remove the solids. The reactor advantages are high COD loadings, relatively small reactor volumes, and operational simplicity. The main limitations are the cost of the packing material and operational problems and maintenance associated with solids accumulation and possible packing plugging. The reactors are best suited for treating wastewaters with low suspended solids concentrations.

## Attached Growth Fluidized Bed Reactor:

The attached growth anaerobic fluidized bed reactor (FBR) is operated at higher upflow liquid velocities of about 20 m/h to provide 100 percent bed expansion. The advantages for FBR process includes the ability to provide high biomass concentrations and relatively high organic loadings, high mass transfer characteristics, ability to handle shock loads due to its mixing and dilution with recycle, and minimal space requirements. The reactor is best suited to treat soluble wastewaters due to its inability to capture solids. Organic Removal Efficiencies of 20% were achieved at loading of 4 kg COD/$m^3$/day [15].The disadvantages includes need for a good flow distribution, pumping power for operation, Packing material costs, need for control of packing level and washing with biogrowth, and length of start-up time.

## Anaerobic Sequencing Batch Reactor:

The Anaerobic sequencing batch reactor (ASBR) process can be considered a suspended growth process with reaction and solid-liquid separation in the same vessel. The operation of the ASBRs consists of four steps: (1) Feed, (2) React, (3) Settle and (4) Decant/effluent withdrawal. During the react period, intermittent mixing for a few minutes each hour is done to provide uniform distribution of substrates and solids [16-17].Sequencing Batch reactor has been developed on basic scientific assumptions that periodic exposure of microorganisms to defined process conditions is effectively achieved in fed batch systems in which exposure time, frequency of exposure, and amplitude of respective concentration can be set independently of any inflow conditions. SBR technology differs in various ways from conventional technologies used in biological treatment of wastewater. The most obvious difference is that the reactor volume varies with time, whereas it remains constant in traditional continuous flow systems. SBR processes are known to save more than 60% of expenses required for conventional activated sludge process in operating costs [18]. A critical feature of the ASBR process is the settling velocity of the sludge during the settling period before decanting the effluent. Its advantages are simplified process, compact facility and flexible operation, solid separation enhanced by quiescent settling. Its limitations included complicated process control, disrupted operation due to high peak flows, equalization requirement prior filtration and disinfection and higher maintenance requirements.

## Hybrid / High Rate Reactors:

High Rate filters provide high sludge retention times by means of sludge recycling which results in maximum efficiency at short hydraulic times. Selection of appropriate reactor configuration is critical to successful operation and requires detailed operation. [11]. Hybrid filters show high and improved stability towards resistance to inhibitory compounds. However, performance of the hybrid reactors with concentrated wastewater has been shown to be poor.

## Membrane Separation Reactors:

Membrane Separation has been considered for anaerobic reactors, but the technology, is still in a developmental stage. The potential advantages of using membrane separation technology are

- Using higher biomass concentrations in anaerobic reactor to further reduce its size and increase volumetric COD loadings.
- Allowing much higher SRTs in the anaerobic reactor by almost complete capture of solids that could result in maximum removal of VFAs and degradable soluble COD substances to provide a higher quality effluent.
- Maximizing capture of effluent suspended solids to greatly improve effluent quality from anaerobic treatment.

The major design considerations for application of membrane separation in biological reactors are membrane flux rate and ability to prevent fouling of membrane to sustain acceptable flux rates. Further developments in membrane design and fouling control measures could make membrane separation anaerobic reactors a viable technology in the future [5].

## CONCLUSION

1. A number of reactor reactors (e.g. batch reactors, complete mix reactors, plug flow reactors, bio-film reactors, suspended reactors, upflow anaerobic sludge blanket reactor, anaerobic baffled reactor, upflow packed-bed attached growth reactor, attached growth fluidized bed reactor, anaerobic sequencing batch reactor, hybrid / high rate reactors, membrane separation reactors).have been developed in the last two decades for applications to industrial and municipal wastewater treatment.
2. Some reactors like Anaerobic Wastewater Treatment Reactors receive great attention over the past decades due to their numerous advantages such as low energy consumption, low chemical consumption, low sludge production, vast potential of resource recovery, less equipment required and high operational simplicity. However, conventional anaerobic systems are found to have operational limitations in terms of long hydrogen retention time (HRT), space requirement and facilities to capture biogas. The applications of newly developed high rate reactors address these limitations and provide increased organic matter removal at shorter HRT and higher methane yields for biogas production.
3. Most of the integrated reactors reported in this work lack large scale implementation within industry and further work is required to evaluate the performance of these promising reactors on a larger scale. Besides, further improvements such as installation of biogas capture system and utilization of suspended carrier or packing medium are considered essential.

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