COMPARISON BETWEEN AEROBIC AND ANAEROBIC WASTEWATER TREATMENT

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Abstract: From the beginning it was a competition between the aerobic and anaerobic method for wastewater treatment. The paper makes a short presentation of the principles of aerobic and anaerobic system with the advantages and weaknesses of each of them. The evolution directions and utilities possibilities are also exposed. The conclusions of this comparison are presented in the final capitol.

Keywords: water treatment**,** aerobic, anaerobic, solid state fermentation, methane.

1. INTRODUCTION

Until the beginning of the 20th Century, common sewage treatment was land spreading. From this, trickling filter treatment was developed. Due to the increasing amount of concentrated sewage, scientists looked for intensive treatment without the aid of filters. Since 1890 trials were made to relieve obnoxious conditions arising from wastewater, by blowing air through the water phase. It was around 1912 that a big advance was made, not discharging the flocculent biological solids, but using them over and over again. The principle of "activated sludge" was first described by Ardern and Lockett (1914) and later by Sawyer (1965). Consequently, all together, aerobic treatment is about 100 years old. Only in recent years the emphasis of aerobic wastewater treatment truly shifted from the technological hardware to the biotechnological software.

At the end of the 19th century, the important advance towards anaerobic treatment of the suspended solids of wastewater was made. The industrial approach of sludge digestion was realized at the turn of the century in the U.K. The first heated tank was installed in 1927 in Germany. In contrast to aerobic treatment, the recognition of the biological phenomena occurring in the digestion process started at the same time as this technology came to existence.

Now that both aerobic and anaerobic wastewater treatment can be considered as having been upgraded to the level of scientific recognition, it is useful to evaluate to what extent both technologies are currently evolving, either as complementary to one another, as it tended to be in the past, or as direct competitors. Both in aerobic and anaerobic treatment have an urgent need for better control and regulation. Particularly on- line monitoring of the biologically removable load and of the possible presence of toxicants is necessary, to improve both types of processes as well as their combined application

A broad overview of criteria directly applicable to wastewater treatment is given in Table 1. Evidently, such listing is only qualitative and the choice of items listed is subjective.

The first step to improve the technology relates to the very basis of aerobic treatment, is the fact that microbial biomass, after having adsorbed and partially metabolized the soluble and colloidal organics, flocculates and settles out, so that a clear effluent is obtained. European research centres, in particular, have contributed to a better biotechnology of activated sludge floe formation , and we name Van Den Eynde in 1984; Rensink in 1982, Verstraete and Van Vaerenbergh in1986, etc. They make now possible to operate activated sludge with a fair degree of insight and control.

Table 1: Listing of criteria applicable to wastewater treatment

Criterion	**Aerobic**	**Anaerobic**
Range of water that can be treated	+	
Process stability and control		+
Volumetric loading rates applicable		+
Power input		+
Heat input	+	
Surplus "fudge production		+
No Nutrient requirements		+
No Oxygen requirement		+
Degree of BOD removal	+	
Degree of NOD or N removal	+	
Degree of P removal	+	
Production of valuable by-products		+
Chlorinated organics may be degraded	+	

2. AEROBIC TREATMENT

A factor hampering aerobic wastewater biotechnology is the relatively low density of the microbial biomass in the reactor. Due to the settling problems, the amount of biomass in the mixed liquid was to be kept in the range 3 - 5 kg volatile suspended solids/m^3. The most obvious solution to this problem is to allow the biomass to anchor to a heavy carrier, such as sand particles, and to operate the reactor as an up flow fluidized bed. Biomass densities up to 30 kg/m^3 can be attained and volumetric loading rates surpassing those of conventional activated sludge by a factor of 10 can be reached accordingly. Yet practice does not yet accept this breakthrough. The reasons for this are probably two-fold. First, fluid bed technology increases the complexity of the treatment and involves the need for intensive control: conventional systems are quite simple and only controlled extensively. Second, fluid bed technology focuses on rate of removal per unit reactor volume: the major element in aerobic treatment is quality of the end-product.

A series of changes in aerobic treatment can be grouped under the common denominator of "easier and more economic design and operation". Table 2 lists some recent European developments. They point to the major weaknesses of aerobic systems.

Of particular interest, in this decade, is the factor of control by computer technology. A major asset of the aerobic systems is their capacity to handle all kinds of wastewaters, especially those with extremely variable composition and even, from time to time, toxic pulses. Yet, although robust, these systems can not cope with everything. It was reported that even well attended aerobic wastewater treatment plants, facing no major shocks or toxic pulses, are currently not meeting the discharge standards around 20% of the time.

Up to now, no on-line big-monitoring devices, capable of quantifying the incoming load and possible toxic pulses as well, and translating this information to the operation control system of the reactor continuously, have been developed. It is likely, however, that in the coming years, an advance along these lines can be expected. This will undoubtedly improve the attractiveness of aerobic treatment in general, and of variable industrial waste-streams in particular.

Table 2: Overview of the aerobic wastewater treatment

Parameter	**Principle involved**
Improving oxygen supply	Measuring oxygen uptake rate in bypass reactor Measuring short-term BOD
Decreasing sludge	Monitoring NO_3 levels Increasing cellular maintenance by imposing pressure cycles in a deepshaft reactor
Integrated control	Dynamic models relying on on-line measurements
Decreasing plant surface and/or construction costs	Bio-tower reactor systems A-B system Unitan

Wastewater treatment is no longer a matter of removal of the bulk of soluble and particulate organic matter. The removal of nitrogen through nitrification and denitrification has been recognized as a process step of major importance. By careful regulation of the oxygen supply, it is possible to have nitrification at the outside of the sludge floes, while denitrification of the nitrate thus formed prevails in the oxygen-limited inner space of the same floe. In this way, not only the nitrogenous pollutant is removed, but also the energy invested in the nitrification step is entirely recovered, because the nitrate ion serves as alternative electron acceptor for the facultative aerobic microorganisms. Obviously, nitrogen removal through on-line regulated nitrification/ denitrification is a great asset of aerobic microbiology. The biological removal of mineral phosphate from wastewater based on the special characteristics of certain aerobic bacteria to accumulate phosphorus has been experimentally explored for about a decade and doesn't pose major technical problems.

Finally, a series of approaches relating to improvement of the metabolic diversity and affinity of the aerobic microbial community should be mentioned. By providing, in the mixed liquor, matrices on which the microorganisms can colonize, one can obtain a more diverse microbial community, comprising both immobilized and free floating organisms. Some approaches along this line are: the addition of polyurethane foam sponges, the addition of powdered activated carbon, the combination of a trickling filter directly to the activated sludge process and the installment of plastic packing in the activated sludge basin.

3. ANAEROBIC TREATMENT

The anaerobic digestion has existed as a technology over 100 years. It gradually evolved, from an airtight vessel and a septic tank, to a temperature-controlled, completely mixed digester, and finally to a high rate reactor, containing a density of highly active biomass. The microbiology of methane digestion has been examined intensively in the last decades. It has been established that three physiological groups of bacteria are involved in the anaerobic conversion of organic materials to methane. The first group, of hydrolyzing and fermenting bacteria, converts complex organic materials to fatty acids, alcohols, carbon dioxide, ammonia and hydrogen. The second group of hydrogen producing acetogenic bacteria converts the products of the first group into hydrogen, carbon dioxide and acetic acid. The third group consists of methane forming bacteria, converting hydrogen and carbon dioxide or acetate to methane.

In contrast to aerobic degradation, which is mainly a single species phenomenon, anaerobic degradation proceeds as a sequence process, in which several sequent organisms are involved. Overall anaerobic conversion of complex substrates therefore requires the synergistic action of the micro-organisms involved. A factor of utmost importance, in the overall process, is the partial pressure of hydrogen and the thermodynamics linked to it.

Another factor of fundamental importance has been the identification of new methanogenic species, and the characterization of their physiological behaviour. Of particular interest was the determination of the substrate affinity constants of both hydrogenotrophic and acetotrophic methanogens. While the first exhibit quite high substrate affinities and remove hydrogen down to ppm levels, the second group appears as yet to contain species with only low substrate affinities. This limited substrate affinity has an important consequence for anaerobic wastewater treatment.

A technological advance of utmost importance in anaerobic digestion has been the development of methods to concentrate methanogenic biomass in the reactor, especially in very low solids concentration in the wastewater, 1 - 2%. Such higher concentration of biomass can be achieved by the principle of autoflocculation and gravity settling as, for instance, in the UASB reactor, by attachment to a static carrier (anaerobic filter), by attachment to a mobile carrier (fluidized bed), especially

For insoluble organics, the major advance made during the past decade relates to solid state fermentation (SSF), also known as dry anaerobic composting. Currently, several successful technologies to digest particulate organics at high rates, in solid state fermenters, are available. Of particular significance is the fact that, with systems operating in the thermophilic range (50 - 60°C), not only high volumetric conversion rates are obtained, but also a stable and hygienic end product, humus. Interesting progress has also been made on direct anaerobic treatment of wastewaters at low temperatures (8 - 25°C). Reactors with granular sludge beds and with polyurethane carrier matrices have been shown to hold potential for direct treatment of domestic wastewaters .

Besides the advances reported above, several other developments are currently occurring in the anaerobic treatment of wastewaters. As for aerobic treatment, they are indicative of specific weak points of the technology involved. For instance, information is constantly increasing with regard to the competitiveness of methane producing bacteria (MPB), relative to sulphate reducing bacteria (SRB). The low energy levels of the substrates introduced, and the high biomass wash-out rates both, appear to favour MPB at the expense of SRB.

Anaerobic digestion is assumed to be more sensitive to toxicants than its aerobic counterpart. Though not a misconception, this assumption currently requires re-evaluation. Three main factors determine the capacity of a biological treatment system to cope with toxic and recalcitrant chemicals: the nature of the chemical conversions; the ecophysiology of the microorganisms involved; and process design and plant operation.

3.1. Anaerobic treatment systems for municipal wastewater

If anaerobic processes could be shown to treat dilute wastewater consistently and reliably, it would be a highly significant development in wastewater treatment. Since anaerobic fermentation results in a lower cellular yield, less sludge is generated, and hence lower sludge handling costs would be possible. In addition, lower energy requirements would result, since aeration would not be necessary, and methane would be produced as a byproduct. In fact, the treatment of wastewater might be a net energy producer.

Originally, anaerobic treatment was the preferred process for domestic wastewater management. Imhoff modified the septic tank for wastewater treatment in Germany, and by 1933 the Imhoff tank was used by over 240 towns in Germany. In general, these early processes were poor for removal of soluble BOD but were successful in capturing solids. Thus the anaerobic processes were abandoned, in practice, for liquid municipal wastewater treatment, with the development of stricter effluent standards and, until the middle part of the 1970s, the anaerobic fermentation process was not considered practical for treating low strength wastewater (BOD<500 1000 mg/l). Some of this problems was resolved by the new generation of anaerobic reactors (the anaerobic fluidized bed, anaerobic filter, and up flow anaerobic sludge blanket processes).

3.2. Anaerobic filter

There have been numerous reports on the development of the anflow process, an anaerobic filter type process, from lab to pilot demonstration scale. At hydraulic retention times of 9 - 10 hours and a loading rate of 0.25 kg/m^3 /day for both TSS and BOD, 80% TSS removal and 70% BOD removal were achieved. This degree of efficiency was maintained in cold weather (=12°C water temperature) but the rate of solids accumulation in the reactor was higher, and methane production decreased. The primary mechanism for the initial removal of TSS (and consequently much of the BOD) appeared to be biophysical filtration, thereby explaining why removal efficiency was not affected by temperature. The concentration of entrapped solids increased continually throughout the study period, but a management plan to remove such solids periodically was necessary. There have been other lab scale evaluations of the anaerobic filter for domestic wastewater treatment with similar findings.

3.3. Anaerobic extended and fluidized beds

The theoretical and experimental researches was made on the development of the anaerobic expanded bed process, and was found how to convert dilute organic wastes to methane at low temperatures and at high organic and hydraulic loading rates. There was testing pilot scale anaerobic fluidized bed reactors used sand as carrier and granular activate carbon (GAC). Some experiments with reactors with

Seeding experiments indicated that the GAC developed a biofilm more quickly and had more attached biomass. In addition, better BOD removal was observed with the GAC reactor. In the same time the removal efficiencies were essentially independent of organic volumetric loading rates.

3.4. Upflow Anaerobic Sludge Blancket studies

The upflow anaerobic sludge blanket process (UASB) is by far the most widely studied reactor configuration for domestic wastewater treatment. Its primary use is for the treatment of higher strength industrial wastewaters, but it can be used for lower strength municipal wastewater - especially in tropical areas. At temperatures exceeding 12°C, COD removal efficiency was around 60% and was not greatly influenced by temperature, loading rates, or HRT. At temperatures below 12°C, removal efficiency was significantly lowered. In later studies (using granular sludge as seed material), it was concluded that conventional UASB technology was not attractive for treating very dilute and very septic sewage under cold climate conditions. The authors noted the importance of good feed inlet construction for obtaining better contact between the immobilized organisms and the influent wastewater. Better contact of organisms and wastewater can be achieved by a) greater height/diameter ratio, and b) recirculation of the effluent, which results in an expanded granular sludge bed (EGSB). The EGSB reactors had better contact and showed improved removals of soluble pollutants, making the EGSB look more attractive for treating cold and low strength wastewaters, after primary settling.

4. CONCLUSIONS

1. Aerobic microbial communities have several specific advantages. They have large free energy potentials, enabling a variety of often parallel biochemical mechanisms to be operated. These communities are therefore capable of coping with low substrate levels, variable environmental conditions and multitudes of different chemicals in the influent.

They have some very useful capabilities such as nitrification, denitrification, phosphate accumulation, ligninase radical oxidation, etc. which make them indispensable in waste treatment.

2. Anaerobic microbial communities are specifically advantageous at high temperatures and high concentrations, of soluble, but particularly of insoluble, organic matter. They also have special physiological traits, such as reductive dechlorination.

3. In the near future, important progress can be expected with regard to the optimal linkage between anaerobic and aerobic processes. Aerobic treatment needs to be specifically focused on the removal of the soluble pollutants.

4. Both in aerobic and anaerobic treatment there is an urgent need for better control and regulation. Particularly on- line monitoring of the biologically removable load (BOD, NOD) and of the possible presence of toxicants is necessary, to improve both types of processes as well as their combined application.

5. It is evident that a long solids residence time (SRT) is necessary for the treatment of sewage by anaerobic processes, because of the low specific growth rates associated with anaerobic bacteria.

6. Fixed-film microbial growth provides intimate contact between the various anaerobic bacteria, thereby providing rates of reaction and degrees of stability which cannot be obtained in suspended growth systems.

7. Up to 1988, either the expanded (or fluidized) bed reactor or the UASB reactor appeared to offer the most desirable configurations for anaerobic sewage treatment. Expanded or fluidized beds have the advantage of hydrodynamic control of film thickness and density, factors which allow them to achieve extremely high

biomass concentrations; however, they are more mechanically complicated. They can be improved to a certain degree by increasing the recirculation rate (such as the EGSB).

8. Control of film thickness and density is not currently possible in the anaerobic filter. This places a relatively high lower limit on the HRT that can be utilized, and can eventually lead to process failure by plugging. In general, however, there is a need for more information on the influence of various engineering variables on film density and thickness, especially hydrodynamic factors.

9. In general, the UASB reactor did not use primary treatment, while anaerobic expanded or fluidized bed reactors did. The reason for this lies in the mechanisms of particle entrapment and hydrolysis in the two systems.

10. If secondary treatment is required, the prevention of solids inventory and handling problems, due to the buildup of inert solids in a reactor with long SRT and short HRT would dictate the need for primary treatment. If secondary treatment is not required, one could use a shorter SRT to achieve the required treatment objectives, and both solids reduction and soluble organics removal could be accomplished in the same reactor.

11. The fate of various wastewater fractions in an anaerobic reactor must be examined, to determine what are the constituents which make up the influent and effluents from these reactors, and whether some pass through untreated. Much of the data in the literature shows that removal efficiencies for sewage have little correlation with organic volumetric loading rate, suggesting that certain constituents in sewage have such low degradation rates, anaerobically, that they are only slightly removed, even under the lowest loading conditions. If these constituents are aerobically degradable, then the effluent from even a "perfect" anaerobic reactor may require further polishing before discharge to a stream, requiring secondary treatment.

12. Another open question is the impact of temperature on the kinetics of biodegradation of various fractions. At low temperatures there may be some materials whose rate of degradation is so low that appreciable removal could not be achieved even at a very long SRT. If that is the case, then anaerobic sewage treatment may be economically feasible only in warmer climates.

13. A better understanding is also needed of the distinction between the destruction and conversion of organic matter, and the coagulation and removal of particulate organic matter. The use of solids filtration in conjunction with an anaerobic reactor might be a useful combination.

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