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LITERATURE REVIEW

a) Facultative Ponds:

In the Report on Seminar (1955) held at Kandy in Ceylon on Sewage Disposal (Rural and Urban) by the W.H.O. for South-East-Asia, it is stated that although sewage lagoons have been used in several western countries as a satisfactory technique for treating sewage, as yet, it has not been deliberately applied in any country of Asian origin. Since then, it is gratifying to record that attempts have been made at Nagpur (Modak 1960) and (Others 1961) to purify sewage by the facultative oxidation pond method from which it was concluded that a loading of 500 lbs per acre per day could be easily applied to get a reduction of 72% in BOD with a retention period of two days. Lakshmi-narayana et al. (1963) continuing the above experiments at Nagpur studied the relation between detention time and BOD removal, and stated that with an average loading ranging from 320 to 800 lbs. per acre per day a higher degree of purification was possible at five feet operational depth with 4 days, 2 days and 1.5 days detention periods. Parhad and Rao (1963) have stated that mechanical aeration has little effect on

bacterial reduction which amounted to 81 to 98.6%; that various groups of bacteria were responsible for stabilization, some of which were perhaps more active than Coliforms and entero-cocci; and that intestinal pathogens belonging to Salmonella and Shigella groups seemed to be eliminated.

Jagannath Rao and Sharma (1963) treated the domestic sewage of Bhopal by this process and obtained a BOD reduction varying from 35 to 50% only, but a Coli count reduction of about 99%, Basu (1963) obtained a 5-day BOD reduction of 78% in a 7 acre pond having a depth of 3 to 3.5' with an influent 5-day BOD at 20°C of about 230 ppm. Murty et al. (1963) carried out pilot plant experiments with the sewage of Hyderabad and obtained a BOD reduction of nearly 70%. Khanade (1963) who estimated the quantity of amino-acids in the oxidation ponds of Ahmedabad found that the domestic sewage contained more than mixed sewage (containing domestic sewage to textile wastes in the proportion of 3:1); and that there was a significant reduction in both forms of amino-acids in the effluents from oxidation ponds.

Even in the west information has been furnished only for the criteria on rational designing. For

example Oswald and Gotaas (1957) and Gotaas and Oswald (1955) have developed design criteria for oxidation ponds taking into account both the controllable and non-controllable factors in the operation of stabilization ponds. Duttweiler (1963) has proposed " a simplified mathematical model based on an assumed upper layer of complete mixing where temperature is isotropic and a lower layer where heating is by vertical eddy conduction alone. The model required testing and verification". Suwannakaran and Gloyna (1963) have evaluated under laboratory conditions the effect of temperature and organic loading on the performance of waste stabilization ponds with a view to establish better design criteria. They found that within limits the BOD removal increased with the increase of temperature; changes in biological activity due to temperature **fluctuations** influenced the pH, MPN of Coliforms, suspended solids, light transmission, predominant algal species, and the required pond volume and that excessively long detention period did not result in better BOD reductions. They claimed that it was possible to formulate a design equation taking into account both temperature and pond loading. Van R Marais (1962) has presented a rational theory for the design of sewage stabilization in tropical

and sub-tropical areas of Africa based on the correlations of the kinetics of BOD and faecal bacterial reductions in a series system of stabilization ponds.

One of the most complete studies on oxidation ponds was carried out by the USPHS at Fayette, Mo., by Neel et al. (1961). "Five identically sized oxidation ponds were loaded at 5-day BOD loading rates of 20, 40, 60, 80 and 100 lbs/acre/day. These data showed that oxidation ponds were very efficient at BOD, phosphate and nitrogen reduction".

Parker (1962) has furnished data on eight oxidation ponds, working in series for a six week summer and winter periods. The first 2 ponds were anaerobic and the last six were aerobic. The BOD reduction was excellent throughout the ponds. Nitrogen removal was insignificant through the first 5 ponds but showed a definite reduction by 8th pond. In winter also, they showed a satisfactory BOD reduction and confirmed poor nitrogen removals.

Bogan et al. (1960) made a study on the removal of P by algae in an effort to remove this key nutrient from sewage effluents. It was found that P was removed

primarily by chemical precipitation rather than by biological metabolism.

Bush et al. (1961) studied the use of algae as a tertiary device for removing minerals from an activated sludge effluent. Natural gas was burned to furnish a continuous source of CO_2 for algal growth and to maintain a pH between 7.0 and 8.5. There was a maximum removal of 38% Ca, 44% Mg, 90% removal of HCO_3 , 41% of sulphate, 76% of phosphates and 100% N. The algae grew on the sides of the treatment Unit. There are only a few references — Myers (1948), Silva and Papenfuss (1953), Allen (1955), Neel and Hopkins (1956) and Merz et al. (1957), which deal mainly with the quantitative and qualitative growth studies of algae in sewage oxidation ponds.

In the transactions of the 1960 Seminar on "Algae and Metropolitan Wastes", the Seminar was limited to discussion of prevention and control of objectionable blooms of algae resulting from enrichment by urban and other wastes. The first symposium on Waste Stabilization Lagoons was held in Kansas city in August of 1960 and the Second International Symposium for Waste Treatment lagoon was held in June

23-25, 1970 at the same place. In the Second Symposium there was an attempt at re-evaluation of the existing design criteria, operating methods etc., in the whole field of lagoons and was particularly devoted to evaluation of results, operating methods and design criteria for the newly emerging aerated lagoon which is getting more and more into prominence. Aerated lagoons and aerobic lagoons differ vitally in engineering details, methods of operation, in biochemistry and microbiology. The former is more related to the activated sludge process and McKinney's "activated algae" process is a hybrid of the two types. More of this later.

Also several investigators have found indications of anti-biotics being liberated by certain species of algae. Oswald, Gotaas, Ludwig and Lynch (1953-a,b) have found a low bacterial population in presence of Chlorella compared to bacterial population attained in systems in the absence of the algae and systems containing Euglena gracilis. In the systems containing Chlorella despite the availability of oxygen in the culture they found that the BOD of the clear supernatant was higher as compared to that obtained for Euglena supernatant. The BOD of the

whole effluent was similarly higher than that of the influent sewage for all but the shortest retention periods. Similar findings have been reported earlier by Galdwell (1946). So, there is some factor inhibiting bacterial action upon the sewage substrate when Chlorella are present. Spoehr et al. (1949) have determined the nature of the antibiotics liberated by Chlorella pyrenoidosa.

It has been recognized that the presence of certain compounds which may be present in waste or liberated as extra-cellular products during photosynthesis may interfere with the photosynthetic process and thereby reduce the effectiveness of algal-bacterial symbiosis in waste stabilization ponds. The presence of certain phenolic compounds, pesticides, herbicides and other related organic substances present in waste water may produce toxicity (Thirumurthi and Gloyna 1965, 1967 and Ju-chang Huang and Gloyna 1968-a,b).

The extra-cellularly produced compounds may be either growth-promoting for other organisms (Krogh 1931) or inhibiting (Lefevre and Jakob 1949, Fogg and Westlake 1955; Wantanabe 1951, Fogg 1952, 1958, 1960; Lewin 1956, El-Baroudi and Mowad 1967). Whitton (1965) has reviewed the production of extra-cellular products

of algae and pointed out that some of these products are more active at certain stages of growth than at other stages.

Some algae like Chlorella and Scenedesmus are known to be relatively resistant to anaerobic digestion (Golueke et al. 1957) while others like Chlamydomonas and Euglena die and decay readily under adverse conditions. Nasbaum (1957) has stated that blue green algae and diatoms grow profusely in oxidation ponds and to comprise the bulk of suspended algal population. Some workers have been able to show antagonism between various species of algae (Swanson 1943).

Fitzgerald (1969 p. 368) has stated "The role of bacteria as possible factors in the control of dominance in phytoplankton blooms in sewage ponds and in the lakes (3) is also suggested from the data on the bacteriasized inhibitor which prevented the growth of Microcystis aeruginosa (Wis. 1036) in sewage plant effluents but did not affect the growth of Chlorella".

"It could be that each species of alga could support the growth of certain bacteria and specific nutritional conditions such as nitrogen limited growth.

These bacteria may not affect the algae they were associated with but might inhibit the growth of competitive algae. The fact that mixture of algae occur at some time and that at other times some of these species occur in almost unialgal conditions, especially blue-green phytoplankton in eutrophic lakes, seem to support the idea that the antagonistic factors involved are only present under certain conditions. Furthermore, it has been demonstrated that the factors which allow blue-green algae to exist as unialgal populations in some lakes are very labile and disappear when the dominant blue-green species is selectively killed with toxic chemicals so that within 4 days a new species can reach effective dominance".

Fink and Herold (1957) have carried out animal feeding experiments with sewage-grown algae and found how beneficial they were in preventing action on liver necrosis. Cook (1962) has estimated the nutritive value of sewage-grown algae.

b) Activated algae:

McKinney and Waheb (1968) have introduced the concept of "activated algae" and suggested that a

combination of bacteria and algae in a controlled treatment process would remove the algal nutrients from waste waters, which would otherwise stimulate algal blooms in receiving waters. Goodman and Weis (1968) have reported on the preliminary development of a full scale, "activated algae" process, discussed the difficulties involved and the lack of data to evaluate properly the feasibility of such a large scale treatment system.

Humenik and Hanna (1970) demonstrated that a symbiotic algal-bacterial culture could be developed and maintained; that the culture could remove nutrients efficiently in a properly designed system using Chlorella pyrenoidosa as the algal organism. Maximum and most consistent removal of influent COD and organic N was obtained during unaerated operation with daily harvesting of algae. But no appreciable phosphorus uptake was observed. Supplemental aeration did not improve nutrient removal, and it was considered as a wasted energy input for an optimally functioning symbiotic algal-bacterial cultures. The culture of the biomass was a natural mixture of algae and activated sludge in which Chlorella became integrally emmeshed within the bacterial matrix. The algal-bacterial floc

settled very rapidly under optimum conditions yielding a clear supernatant.

c) High-rate aerobic Ponds:

The high-rate oxidation pond has been studied in New Zealand (Hicks 1958), Taiwan (Spong, 1961), at Ahmedabad, India (Ganapati et al. 1965) and in Australia (McGarry, 1967).

A high-rate pond research programme has been recently initiated at Bangkok in Thailand at the Asian Institute of Technology (McGarry and Tangkasame 1971). In the last place, research has been done at laboratory and pilot plant scales. Twenty-four experimental ponds were constructed for the treatment of diluted settled night soil. Twenty-seven pond conditions were studied with combination of the levels of variables such as loading, depth and detention period. The ponds were mixed daily by brooms at 9.00 a.m. and 7.00 p.m.

Efficient waste water treatment and high yields of algae are achieved through the operation of a high-rate pond at 200 lbs BOD/acre/day loading, 17.7" depth and 1 day detention time. Under these conditions

effluent BOD/algae removed is lower than 10 mg/l and an acre of pond can produce about 100,000 lbs or 45,400 kg of algae/dry weight per year. At solar energy levels of 480 gram-calories/sq.cm/day, 2,800 lb/day (1270 Kg/day) of dried algae (with less than 10% moisture can be produced on one acre).

An urban model has been suggested that incorporates re-cycling of reclaimed pond effluent (after treating with alum or alum plus poly-electrolytes) for household cleaning purposes. Potable drinking water would be supplied through a separate distribution system. Use of such a dual distribution system would effect a two-third reduction of conventional water supply requirements.

"Research on the system under tropical conditions is now required in the fields of animal nutrition, product processing, market analysis, and process economics, both at the pilot plant and photo-type scales (McGarry and Tangkasame 1971).

Ganapati et al. (1965) have described the type of high-rate aerobic lagoons which were in use in the Pirana Sewage Farm at Ahmedabad, India. In the extensive farm of 2850 acres on the eastern bank of

the river Sabarmati, broad irrigation was carried out on 2500 acres and the remaining 350 acres at the farthest end of the farm were converted into 280 plots of "Solar drying beds", where, raw settled sewage, not required for irrigation was stored to a depth of 2 to 27 inches and allowed to percolate and to evaporate in the sandy soil on the bank of the river. The algal solids were removed finally from each bed and sold as manure.

Impounding raw settled sewage (which had travelled over a distance of six miles in narrow open channels with a self-cleaning velocity) was practised as a distinct treatment method since 1932. Two distinct processes were taking place in the ponds: (a) synthesis of profuse green and blue-green algal organisms making use of the fertilizing elements of sewage and (b) concomitant release of large quantities of dissolved oxygen. The 282 ponds were examined for their physico-chemical and microbiological conditions during the different seasons of 1961-62; and the results have been published.

The so-called "solar drying beds" of Ahmedabad resemble in important respects the high-rate aerobic ponds in their smaller area and depth with detention

periods of less than one week, where stabilization of sewage ~~was~~ brought about solely by the photophysiological action of green and blue-green algal organisms (Ganapati et al. 1965).

Bhaskaran and Chakrabarti (1966) tried to purify cane sugar waste first by anaerobic digestion followed by "an aerobic oxidation pond 4 ft.(1.2 m) deep at an average BOD loading of 300 lb/acre/day. The overall BOD removal was 70%. Again, Golueke (1960) states: "An extensive knowledge of the ecology of the organisms involved in the process for the treatment of waste in a high-rate oxidation pond is required. This is true because effective biological control requires an optimum relationship between the environment and the biotic community concerned; and this can be accomplished only by providing proper environmental conditions. To establish a relationship, it is necessary to know the nature and extent of the influence of the principal environmental factors which an algal-bacterial community is subject in an oxidation pond".

"There is paucity of information in the literature on the effect of these environmental factors either individually or collectively on such organisms

when living as members of a biotic community. His statement holds good even today.

d) Definition of Symbiosis:

The relationship between organisms has been discussed in several ways. One of them is designated as "symbiosis" to describe the intimate and constant association of two kinds of organisms with reciprocal benefits. There are three types of symbiotic relationships such as "Neutralistic", "Mutualistic" and "Antagonistic" (De Ley 1960). "Neutralistic symbiosis" is the relationship existing between two organisms when they have little or no effect on one another. If one or both participants benefit from the relationship without any injurious effects on the other, this relationship is called "mutualistic". In "antagonistic" symbiosis one of the two participants may or may not derive any benefit from the relationship or one of them may be deleterious to the other. So, it will be seen from the above that algal-bacterial symbiosis in high-rate aerobic ponds may be any one of the three types depending upon the dominant alga and bacterium present in the waste, and it would appear to be "mutualistic".

e) Algal-bacterial Symbiosis:

There are still some scientists who regard algal-bacterial symbiosis in aerobic oxidation ponds as a fiction. Experimental and cited evidence are furnished below to convince them that it is a fact and not a fiction.

It is well known that organic matter in sewage is most rapidly oxidized in the two conventional aerobic methods of biological waste-water treatment (Eckenfelder and Weston, 1956; Eckenfelder and Porges, 1957). There is also much evidence to show that fresh algal organic matter is also most rapidly synthesised on a sustained basis by green algae (Burlew, 1953; Krauss, 1956, & Tamiya, 1957). Laboratory and Pilot plant investigations of sewage carried out during 1951-1955 by Ludwig et al. (1951), Oswald et al. (1953, a-b), Gotaas and Oswald (1955) in the Public Health Engineering Research Laboratories of the University of California, furnished ample experimental evidence that algal-bacterial symbiosis is actually taking place in new or existing sewage aerobic oxidation ponds. For it is generally recognized that the principal products of aerobic bacterial oxidation of organic matter are

CO₂, NH₃, H₂O which, except for the additional requirement of light energy, are exactly identical to the principal requirements for algal photosynthesis. Thus, in theory the decomposition of organic matter by bacteria may occur at the same time that new organic matter is being synthesised by algae, provided that light is available as the energy source. Under such circumstances the efficiency of oxygen utilization is greater because oxygen is used as soon as it is formed. Oswald, Gotaas, Ludwig and Lynch (1953-a p.692) have collected considerable evidence from their experiments on high-rate ponds indicating that the species of algae which are effective in photosynthetic oxygen production utilize NH₃ as the principal source of N with which to build their proteinaceous material from sewage. At moderately long detention periods of 3 to 4 days when light and temperature are optimum, almost all the NH₃-N appears in the form of algal cell materials. Thus N is conserved and at the same time BOD is considerably reduced. Recirculation is very important to photosynthetic oxygen production as it permits the seeding of influent with algal cells, and produces good overlapping of bacterial oxidation and photosynthetic

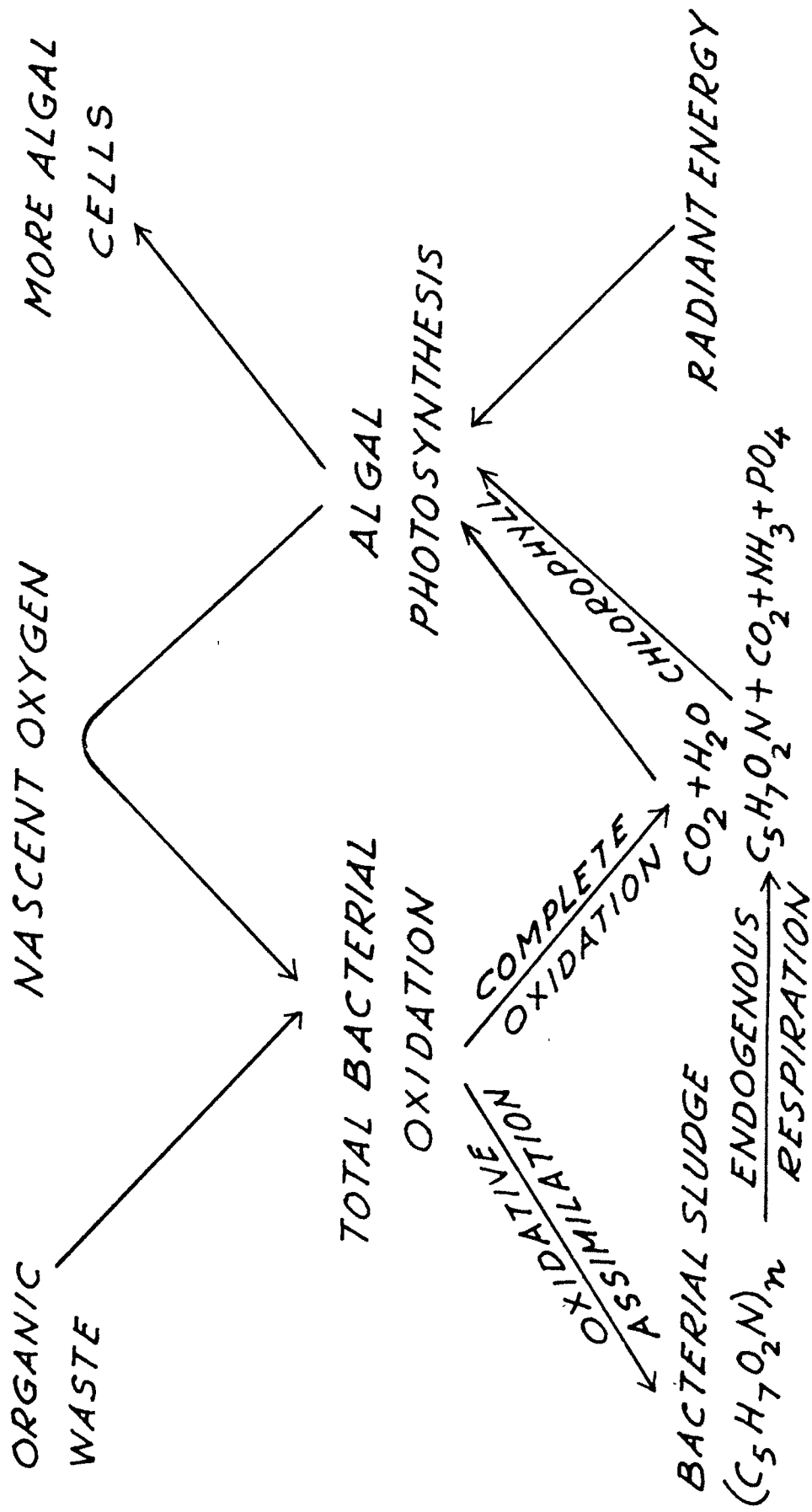
reduction thereby preventing loss of CO_2 and NH_3 from the bacterial phase and also providing an efficient outlet for the oxygen liberated by algal growth (Oswald, Gotaas, Ludwig and Lynch *M*, 1953-b, p.26). This overlapping produces more abundant growth of bacteria and would produce more abundant growths of algae were it not for the problem of sludge deposition. Algae tend to remain dispersed in the solution while bacteria tend to form a floc which together with coagulated sewage colloids containing a large part of C and N settles quite rapidly to the bottom of the pond. Principal benefits of recirculation are (i) seeding and (ii) aeration of the influent.

If continuous vertical mixing is used some aerobic sludge may be carried with the pond effluents. This material may be readily removed from algal suspension by sedimentation and returned to the pond. The retention of sludge is advantageous as it allows more complete oxidation of organic matter, resulting in increased algal growths and improved removal of suspended solids other than algae (Oswald and Gotaas, 1957).

Further studies since then by a host of scientists

FIG. 1

BIOCHEMISTRY OF ALGAL-BACTERIAL SYMBIOSIS IN HIGH RATE AEROBIC POND SYSTEM (MODIFIED OSWALD & GOTHAAS 1958)



in U.S.A.,— chiefly Oswald and Gotaas (1957), Oswald (1960, 1962, 1963, 1964), Oswald et al. (1959-a,b), Oswald and Golueke (1960, 1968), Oswald et al. (1958, 1961, 1964), Golueke et al. (1958,1959), Golueke (1960), McGarry (1971) — have established beyond a shadow of doubt that algal-bacterial symbiosis is really taking place in aerobic sewage oxidation ponds resulting in huge algal production, nutrients removal and purification of sewage. These studies have also provided some basic principles which can be used for engineering design of the process and for the production of operational performance of new or existing ponds. Based on these principles the design criteria have been formulated by these authors.

The cycle of photosynthetic O_2 production and bacterial oxidation of organic matter is shown in Fig. I.

It will be seen from a study of the figure that organic matter entering the system as sewage is oxidised by sewage bacteria using O_2 liberated by algae. The algae in their turn utilizing solar energy are simultaneously synthesising fresh organic matter in the form of algal cells using CO_2 and NH_3 produced

by bacteria. Although this entire reaction may take place in a closed system, some CO_2 is normally drawn into the cycle from the atmosphere and excess O_2 may be lost.

The basic principles on which algal-bacterial symbiosis takes place in a high-rate aerobic pond are shown in the above diagram. In order to develop practical equations for the design of such a unit, it is desirable to assume that it will be operated such that all the O_2 required by bacteria will result from the development of the algal biomass and all the CO_2 required for algal synthesis will result from the bacterial oxidation of sewage organic matter. To evaluate these factors and to express them in simple equations, certain assumptions based on well known facts have been made.