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Removal of Algae from Waste Stabilization Pond Effluents—A State of the Art

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CONTENTS

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REMOVAL OF ALGAE FROM WASTE STABILIZATION POND EFFLUENTS - A STATE OF THE ART

by V. Kothandaraman and Ralph L. Evans

Introduction

Treatment of municipal, industrial, and agricultural wastes employing stabilization ponds or lagoons has found increasing application within the past 20 or 30 years. Where land values are not excessive, the low cost of construction and operation and the demand for less technical competence in their operation compared with more sophisticated treatment facilities make lagooning, in one form or the other, the method of choice for the stabilization of many different types of waste materials.

Regardless of whether the lagoon is an oxidation pond, an anaerobic cell followed by an aerobic polishing pond, or a facultative lagoon, the effluent from each facility is likely to contain a significant concentration of algae. In some areas, notably the state of Michigan, the complete retention of wastewater in oxidation ponds is required except for a few occasional discharges during periods of high water in the receiving streams.[1] Where the total inflow into lagoons exceeds the evaporation losses, there is bound to be effluent discharges unless adequate capacities are provided. The planktonic algae discharged from lagoons have the potential for oxygen production in the receiving stream, but they also represent a significant load of energy-rich organic matter to the receiving stream.

With the adoption of wastewater effluent standards by water pollution abatement agencies, particularly with respect to suspended solids and biochemical oxygen demand, it becomes imperative either to design the oxidation pond facilities on a total wastewater retention basis or to provide means for separating the algae from pond effluents and disposing of the harvested residue.

This report summarizes the investigations of other research workers concerning methods of harvesting algae and disposing of that harvest, and should be helpful to consulting engineers and stream pollution abatement agencies. It was prepared by the Water Quality Section of the Illinois State Water Survey under the general supervision of Dr. William C. Ackermann, Survey Chief. Since several of the separation techniques employed in these investigations are physiochemical processes, a brief introduction to the algal cell wall characteristics is presented before discussing the algal removal methods.

CELL WALL CHARACTERISTICS

Ives[2] first demonstrated experimentally that algal cells carry a negative electric charge and developed expressions for charge density variations. The charge density was found to be a function of the viscosity and dielectric constant of the disperse medium, temperature of the medium, and the concentration and valency of the ionic species in the medium. A suspension of *Chlorella* in distilled water exhibited marked pH dependence of charge densities, as shown in figure 1. The charge density was lowest at a pH of around 7. However, the algae remained electro-negative at all pH values investigated.

Ives[2] postulated that the mechanism of algal removal by chemical coagulants was charge neutralization of the negatively charged algae by the positively charged metal and hydroxy metal ions and subsequent agglomeration and sedimentation. Other previously held theories like mechanical enmeshment, adsorption, and the protogel theory developed by Hay were considered by Ives as secondary in importance for the precipitation of algae.

Golueke and Oswald[3] conducted a series of experiments to investigate the relation of hydrogen ion concentrations to algal flocculation. The relationship between pH levels and the tendency of the algae to flocculate measured by the increase in clarity of the supernatant is shown in figure 2. A pH value of about 3 seems to be a critical point since flocculation was most extensive in this region. The flocculation cells were found to form compact clumps in a fashion indicating direct surface attraction. They postu-

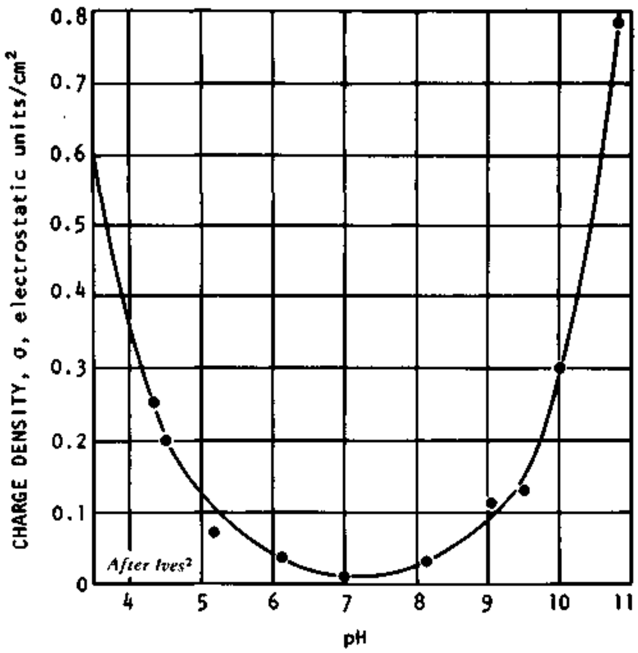

Figure 1. Chlorella — charge density-pH graph

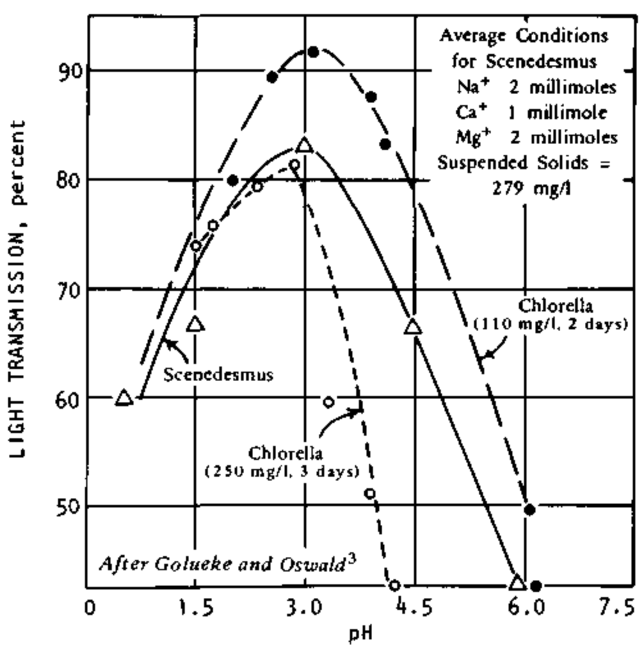

Figure 2. Effect of pH level on tendency of algae to flocculate as shown by the increase in clarity of the supernatant

lated that the free H^+ not only served to satisfy the surface charge of the algal cells but also acted as a bonding agent. The greater the density of surface charge, the more pronounced was bonding. An indication that the H^+ is bound by algal cells was inferred from the fact that an increase in ion concentration was required for maximum precipitation when the algal concentration was increased.

Although harvesting of algae by passage through ion-exchange columns is uneconomical,[3,4] results of ion-exchange column studies reveal much about their surface properties. Golueke and Oswald[4] found that pond algal culture when passed through strong and weak anion exchange resin columns resulted in no algal removal. However they found that algae could be removed by passing an algal suspension through a column either of a strong or weak cation exchange resin. The mechanism of removal apparently involved flocculation that resulted from a change in surface charge of the algal cells brought about by the charge of the resin.

This was demonstrated by the failure of the exchange columns to remove algae after their exchange capacity had been exhausted and their renewed ability following regeneration. The changed characteristics imparted to the algal cells persisted even after the algae had been removed from the columns by backwash. Algae in the backwash water promptly coagulated and settled. As the columns lost their ion-exchange capacity, the algae also lost their tendency to coagulate. The ion-exchange columns were effective, as far as algal removal was concerned, only when they were regenerated with H^+. Use of Na^+ or of any cations other than H^+ interfered with the algal removal capacity of the columns. Operating characteristics such as throughput rates, regeneration of columns, column lengths, methods of improving the regeneration efficiency, etc., are discussed in detail by Golueke and Oswald.[4]

It appears that the mechanism by which the cells were agglomerated in the presence of free H^+ involves a combination of electrostatic forces and physical changes in the membrane of the cell. It is a physiological axiom that the pH of the medium in which algae are suspended exerts a strong influence on the permeability of the algal cell walls and may change the nature of the walls and affect the surface physiochemical make up of the walls.

ALGAL SEPARATION

Methods and cost of algae removal assume great importance when planktonic algae must be removed from the effluent of a conventional stabilization pond before discharge into a receiving body of water. The mode of final disposal of the harvested algae in turn dictates the methods of algal removal from pond effluents and further processing. Algae intended for animal or human consumption must be processed so that they can be stored for long periods of time without deterioration. When the algae are harvested for their food values, a careful choice of chemicals must be made so that the chemicals do not have any toxic or other deleterious effects when ingested. Gradation in actual and in permissible costs of harvest will range from the lowest for the mere removal of algae, to higher for processing of the algae as a livestock feed, and to the highest for processing algae that are to be used as human food.

Technical and economic problems in algal harvest are largely due to the size, specific gravity, and morphology of the algal cells, their limited concentration and low market value. A combination of small size (5 to 15 microns) and low specific gravity results in a settling rate that is too slow to permit the use of settling as a routine procedure for harvesting algal cells. The small size of algal cells also necessitates the use of screens or filters having a pore size within the micropore range. The limited concentrations, 200 to about 4000 mg/1 in oxidation ponds, involve handling of large volumes of liquid in order to recover a comparatively small amount of product.

Harvesting of algae generally involves three steps.[3,5] The first step, concentration or removal, increases the solids concentration from about 0.02 to 0.40 percent by weight to about 1 to 4 percent. The second step is dewatering which then brings the solids to 8 to 20 percent. Finally in the third step, the algal mass is dried to 85 to 92 percent solids by weight.

Relatively little work has been done on algal separation, especially at pilot scale levels. Oswald and Golueke[3,6] present a comprehensive review of the results of several years of work on the problems of separating algae grown on secondary sewage effluent. Also recently, the California Department of Water Resources[5] reported on the feasibility of nitrate removal from agricultural drainage by an algal system including harvesting of algae, based on pilot scale studies. In general, their results indicate that algae could be most economically concentrated by coagulation, flocculation, and sedimentation. Dewatering was accomplished by centrifugation, with final drying in the open. An alternative to separate dewatering and drying steps was to spread the concentrated slurry on sand beds, which brought about the desired solids concentration without the intermediate step of dewatering. North American Aviation, as indicated in the California Department of Water Resources report,[5] found sand bed dewatering and drying feasible in the harvesting of sewage grown algae. In their studies also, the algae were concentrated by sedimentation after coagulation and flocculation and then spread on sand beds.

Chemical Precipitation

Several investigators have reported on the efficacy of using chemicals, both mineral and organic, for coagulating and precipitating algae from suspension based on laboratory scale investigations.[3,5,7,8,9] Lin, Evans, and Beuscher[7] found that an overall algal reduction in excess of 85 percent in Illinois River water could be achieved using aluminum sulfate at a concentration of about 30 mg/1. Tenny et al.,[9] using mixed cultures of algae obtained from laboratory reactors and organic flocculants, found that algal flocculation occurred only with the addition of cationic polyelectrolytes and not with the addition of anionic and nonionic polymers. They postulated that a bridging phenomenon between discrete algal cells and the linearly extended cationic polymer chains, forming a three dimensional matrix that is capable of subsiding under quiescent conditions, was the possible mechanism involved. A concentration of the cationic polymer (C-31 of Dow Chemical Co.) in the range of 2 to 3 mg/1 at a pH range of 2 to 4 was most effective.

Oswald and Golueke[3] and McGarry[8] found that anionic and nonionic polymers were ineffective in causing coagulation and precipitation of algae. However, the California Department of Water Resources found, on the basis of laboratory scale studies, that a few anionic polymers were experimentally beneficial and economically feasible aids in coagulation. These anionic polymers were not used in pilot scale evaluation.

Golueke and Oswald[3] reported that cationic polyelectrolytes, in the concentration range of 2.5 to 3.0 mg/1, resulted in an algal removal of about 80 to 90 percent. Complete removal of algae was achieved at a concentration of about 10 mg/1. The efficiency of algal removal by the cationic polyelectrolytes investigated were not affected in the pH range of 6.0 to 10.0.

The California Department of Water Resources[5] reported that out of 60 polyelectrolytes tested, 17 compounds were found to be effective coagulants and their costs were economically competitive when compared with mineral coagulants alone. Generally less than 10 mg/1 of the polyelectrolytes was required for effective coagulation. A significant feature of this report is that a daily addition of 1 mg/1 of ferric chloride to the algal growth pond resulted in significant reductions in the required dosages of both organic and inorganic coagulants. After commencing the addition of ferric salt to the algal growth pond, 90 percent of the algae could be removed with 0.5 mg/l of Cat-Floc (cationic polyelectrolyte, Calgon Corp.). The cost of treating 1 million gallons of algal pond effluent at this concentration of Cat-Floc was estimated to be about $2.00. Results of the reduction in mineral coagulant dosages due to the addition of ferric salt to the growth pond were presented also.

McGarry[8] has reported results of factorially designed experiments to optimize the process of chemical coagulation in harvesting algae obtained from a pilot high rate pond. Tests were performed to identify the economically feasible polyelectrolytes used as primary coagulants alone, or in combination with alum, and to investigate the independent variables which affected the flocculation process. Among the conclusions of the author, the significant ones are: 1) alum was effective for separation of algae from high rate oxidation pond waters and 2) the overall minimum cost per unit of algal yield was obtained with alum alone in the dosage range of 75 to 100 mg/l of alum. The polyelectrolytes used in the study did not reduce the overall costs of algal separation.

Speedy, Fisher, and McDonald[10] investigated the effectiveness of various prototype unit processes in a water treatment plant in removing algae from the raw water supply. They came to the conclusion that the use of alum as a coagulant is moderately effective in algal removal. However, use of lime as a coagulant appeared to be much more efficient. They found that different steps of treatment removed different kinds of algae at different rates.

Van Vuuren and Van Duuren[11] reported on the results of removal of algae from the Pretoria (South Africa) wastewater maturation pond effluent. They found that chemical coagulation with either alum or excess lime applied to algae-laden pond effluent yielded an acceptably clear and colorless water. They found also that all the polyelectrolyte coagulant aids at varying concentrations, tested in conjunction with lime or alum, failed to give improved results. The authors chose high concentrations for the primary coagulants, namely 110 mg/l of alum and 220 mg/l of lime, which probably masked the effectiveness of the several coagulant aids tested.

The California Department of Water Resources[5] evaluated the use of lime, alum, and ferric sulfate as primary coagulants during their laboratory and pilot scale studies for harvesting algae. Their experience shows that the concentration required of each of these chemicals to remove the desired amount of algae varied according to the operating conditions of the growth units and was relatively independent of the initial algal concentration.

The concentration of lime needed for 90 percent removal of algae varied from 20 to 200 mg/l. Another benefit as a result of the use of lime as a coagulant was the almost complete removal of phosphorous. However, the pH of the lime treated effluent may have to be brought back to acceptable levels before final discharge to the receiving waters. Alum concentrations of about 50 to 200 mg/l were required to bring about 90 percent algal removal. The requirement of ferric sulfate was found to be about 140 mg/l.

The dramatic effect of the daily addition of 1 mg/l of ferric chloride to the growth pond on required dosages of all three chemicals is illustrated in figure 3. Without any additional chemical, the removal level was increased from 40 to 70 percent, presumably as a result of coagulation by the ferric chloride added for growth. The effective level of $Fe_2(SO_4)_3$ dosage was reduced from 140 to 5 mg/l. The concentrations of both lime and alum were also reduced, with alum being effective at about 20 mg/l and lime at 40 mg/l. However, a steady build up of iron in the supernatant, due to the addition of ferric chloride to the growth pond, was noticed. Shown in table 1 are cost estimates of removing 90 percent of the algae from 1 million gallons of pond effluent.[5] Figures in the table show that the cost of these chemicals for separation of algae may be reasonable and that ferric sulfate is the cheapest of the primary flocculants tested.

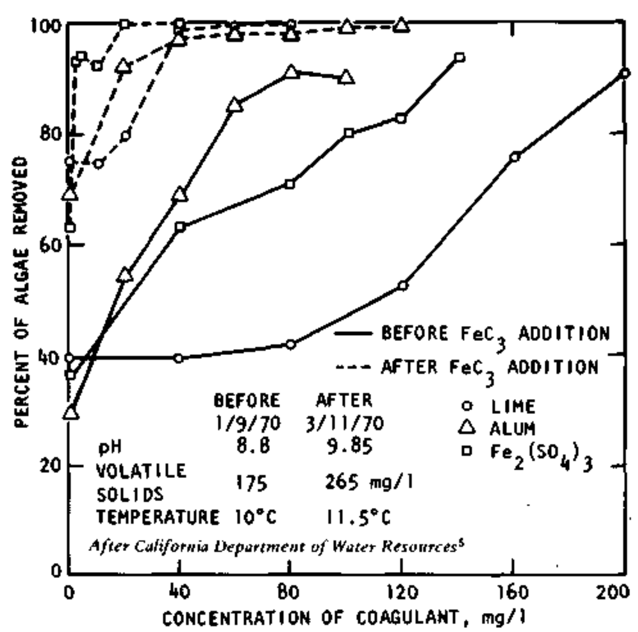

Figure 3. Concentrations of lime, alum, anu rerric sulfate required for 9 0 percent algae removal — before and after addition of ferric chloride to rapid growth pond

Table 1. Estimated Cost of Lime, Alum, and Ferric Sulfate to Remove 90 Percent Total Suspended Solids

Date	Volatile solids (mg/l)	(Dollars/million gallons) Alum	Lime	Ferric sulfate
11/19/69	250	11.30	16.80	14.40
12/03/69	200	12.30	14.60	
12/11/69	100	14.00	20.00	25.00
1/09/70	175	13.30	20.80	23.80
1/16/70	71	11.90	15.90	22.30
1/23/70	91	12.70	8.20	24.40
2/11/70*	114		3.50	11.00
2/18/70	210	13.00	5.40	1.50
2/25/70	417	2.35	1.30	0.25
3/11/70	265	3.46	3.28	0.40
3/18/70	229	3.50	3.23	0.62

Commenced 1 mg/l daily addition of Fe^{+++} to pond on 1/26/70

In their pilot studies, the settling chamber consisted of a module of settling tubes inclined at an angle of 7½° upward in the direction of flow. This was a part of the self-contained water treatment plant called the "Water Boy" manufactured by Neptune Microfloc, Corvallis, Oregon. The slurry taken directly from the tubes contained from 1.1 to 1.6 percent solids. Overnight settling of the slurry increased the percent solids to 4 to 6 percent. However, tests of settling as a function of time indicated that 80 percent of the settling occurred in the first 6 to 8 hours.

Golueke and Oswald[3] reported on the efficacy of algal removal using aluminum sulfate based on laboratory, pilot, and field scale studies. Laboratory studies were concerned with determining the relation between dosage and pH level, the effect of floc aids, of stirring and settling times, the amount of aluminum in the precipitated product, and ways of removing aluminum from the harvested product and of determining the quality of the supernatant. Best removal of algae was obtained when the pH of the suspension was 6.5. Removal became increasingly poorer as the pH was raised above 7.0. A mixing time of 3 minutes was found to be adequate at a blade tip velocity of 12 inches per second. A settling time of about 15 minutes was sufficient.

The greatest yield of algae per milligram of alum was obtained at a dosage of 70 mg/1. However, highest clarity of the supernatant was obtained in the dosage range of 90 to 100 mg/1. In their experiments in which flocculant aids were added in addition to the alum coagulant, no improvement with respect to settling characteristics of the floc particles, clarity of supernatant, or amount of required dosage was noted over that obtained with alum alone.

In the pilot and field scale studies, similar results were obtained. The sediment concentration in the flocculation-sedimentation unit with a detention time of 2 to 3 hours averaged 1.5 percent by wet weight.

The authors found that most of the algae could be removed by raising the pH to 10.6 or above with lime. Very little algal precipitation occurred at pH levels from 9.5 to 10.5. Their results showed that the use of ferrous sulfate as an additive brought about a distinct improvement in precipitation, the extent of which was in direct proportion to FeS04 dosage until a critical point of 40 mg/1 was reached. Above this concentration further gain in clarity was not accomplished. The required dosage of Ca(OH)2 was reduced correspondingly. A combined dosage of 40 mg/1 $FeS0_4$ and 120 mg/1 $Ca(OH)_2$ resulted in a supernatant clarity having 86 percent light transmission; whereas at 200 mg/1 $Ca(OH)_2$ and no FeS04, it was only 78 percent.

The advantage in reduction of cost of chemicals that could result from the use of an iron salt in conjunction with a primary coagulant has to be weighed by the disadvantages resulting from the production of an algal slurry and a supernatant containing iron. Iron in the floc would constitute an undesirable element in algal product used as a feedstuff for livestock, and its excess in the supernatant would make the latter undesirable for discharge into receiving waters.

Centrifugation

Oswald and Golueke[3,6] experimented with centrifuges to determine the effect of feed throughput rates, cell concentration, rotational velocity, underflow discharge rates, power requirements, etc.

Removal of algae from the influent algal culture (concentration 200 mg/l) ranged from 84 percent at a throughput rate of 100 gpm to about 64 percent at 385 gpm at rotational velocities of 3000 to 3300 rpm. The details of the effect of throughput rate, the disc angle and the rotational speed of bowl on power requirements are given in the reference. The authors estimated that the minimum power requirement for concentrating algal culture at a concentration of 200 mg/1 to be about 2.7×10^3 kwh per ton (dry weight) of algae. The power requirements could be halved by doubling the initial algal concentration.

The California Department of Water Resources[5] reported the results of the evaluation of the De Laval self-cleaning centrifuge both as a primary concentration and as a dewatering device. Used as a primary concentrator, the unit removed up to 95 percent of the influent algae (concentration 800 mg/1). The flow through the unit was 6 gpm and the effluent slurry contained about 10 to 12 percent solids. A problem in plugging was encountered because of incomplete discharge of material in the bowl. This problem was solved by an operational procedure called "double shoot." After the change in the operational procedure, a product with 17 percent solids was obtained, but the percent removal dropped to about 80. The self-cleaning centrifuge, used as a dewatering device, was tested with an influent containing 20,000 to 30,000 mg/1 solids. At a flow rate of 2.75 gpm, the slurry contained about 10 percent solids. At that loading, the centrifuge removed more than 98 percent of the influent suspended solids.

Although centrifugation offers the advantage of simplicity and continuity of operation and the production of material high in quality and devoid of additive reagents, it has the obvious economical disadvantages of high initial cost, and relatively high demand of electrical power.

Flotation

Golueke and Oswald[3] reported on laboratory scale flotation experiments. Of 18 different flotation reagents tried in their experiments, appreciable concentration of algae was obtained only with two reagents. Even with those two, the extent of removal was too small to be practical. However, Levin et al.[12] reported a flotation method in which the cell concentration of the harvest is a function of pH, feed concentration, age of the culture, and height of foam in the processing column. A pH level of about 3.0 was found to give best results. Levin et al.[12] used synthetic medium to raise 6 different algal species in their laboratory scale batch-type harvesting studies. Without any chemical additives, they were able to concentrate algae in the foam to the extent of 5 to 8 percent of solids content.

A major disadvantage of this method is the need to reduce the pH of the pond liquid to the required low level and subsequent readjustment to an acceptable level before discharge to receiving waters.

Microstraining

Though successful application of microstrainers in the removal of algae from raw water supplies has been reported,[13,14] their use with pond effluents appears to be very much limited. Golueke and Oswald[3] carried out pilot scale experiments to evaluate the use of microstrainers in algae removal. Flow rates varied from 50 to 100 gpm and the microstrainer was rotated at 10, 20, and 30 rpm. Only very small amounts of algae were removed even with the addition of filter aids, a decrease of flow rates, and slowing of the rotational speed of the filter.

The California Department of Water Resources[5] reported that screens of pore sizes 25 and 35 microns were ineffective in algal removal. Removals up to 30 percent were obtained, but most of this was due to algal settling in the influent and effluent chambers.

Upflow Clarifiers

Upflow clarifier with detention times of about 1 hour was found to be effective in concentrating algae from pond effluents.[5] With an addition of 100 to 200 mg/1 of sodium hydroxide, the upflow clarifier was found to remove as much as 95 to 100 percent of suspended solids and produced a slurry containing 2 to 10 percent solids.

Although the unit did an effective job of removing the algae, many operational problems arose which prevented long run times. The most serious of the problems was caused by the consolidation of the algal mat, which caused increased hydraulic pressure resulting in sloughing of the algal floc. When this occurred, normal operation of the unit did not resume until the mat built up again. Also, the pH of the effluent from the clarifier should be readjusted to an acceptable level before final disposal.

Filtration

Borchardt and O'Melia[15] carried out laboratory scale studies on the removal of uni-algal cells by sand filtration. The effects of variables such as algal concentration in the inflow, sand size, sand depth, flow rate, etc. on head loss and the efficiency of algal removal were reported. The removal efficiency was found to decrease with time and the algal cells were found to penetrate through the sand bed even in the early stages of each of their filtration experiments.

Foess and Borchardt,[16] in laboratory scale studies, reported that the attachment mechanism for discrete algae in sand filtration involved a surface interaction between the particle and the sand grain which can be chemically controlled. Stock cultures of *Chlorella* or *Scenedesmus* in required concentrations were used in their studies. Solution pH was determined to be an effective parameter for controlling the filtration process. When the pH was lowered, making interaction energies between diffuse layers of the sand and algal particles more favorable for adsorption of the two particles, removals significantly increased.

Golueke and Oswald[3] reported on the laboratory scale experiments on filtration with the use of a Buchner funnel and a 3-cm diameter filter leaf. Diatomaceous earth, corn meal, corn starch, and calcined rice hulls were used as filter aids. Effectiveness of paper, fine mesh metal, nylon, cotton, and woolen screens of a wide variety of porosities, as well as teflon cloth (14-20 micron pore size), was evaluated. In the absence of filter aids, algae were able to pass through all filter media tried. Complete removal of cells was obtained when diatomaceous earth, corn starch, and calcined rice hulls were used as filtering aids.

Concentration of algae by gravity filtration does not appear to be promising because of clogging of the filter media with the concomitant increase in head loss and decrease in throughput rates. Frequency of backwashing has to be increased to maintain a desirable filtration rate. No pilot scale or field scale operation of algal removal by filtration has been attempted yet.

Miscellaneous Methods

Golueke and Oswald[3] reported the phenomenon of natural flocculation and precipitation of oxidation pond algal cells under certain conditions. They termed this phenomenon as autoflocculation. The required conditions were an actively photosynthesizing algal mass in a shallow pond, sunlight, and a relatively warm day. Separation of algae by autoflocculation alone would necessitate a large surface area for the pond. The authors advocate the substitution of chemical separation on days when weather conditions are not conducive for autoflocculation.

The same authors examined the possibility of algal separation by sonic vibration and by the passage of the pond effluent through a charged field. When algae were exposed to ultrasonic waves of 15,000 cycles and up, they were dispersed effectively at all of the frequencies tried. Algal separation by passage through an electric field was also tried. Excellent separation of algae occurred when aluminum or copper electrodes were used because of the formation of copper or aluminum hydroxide due to the release of Cu^{++} or Al^{3+} from the electrodes. No separation took place when two carbon electrodes were used. Copper, carbon, and aluminum electrodes were used either as pairs of only one of the materials, or as pairs composed of two different materials. Distance between the electrodes varied from 1/8 to 1/2 inch. Tested flow rates ranged from 0.05 to 1.2 gpm/cu ft of electrolyte cell volume. Current was varied from 0 to 900 milliampers. Applicability of this method on a large scale was not investigated.

DEWATERING METHODS

Algal concentration resulting from the first step of algae separation from the pond effluent varies from 1 to 4 percent by weight. For economical handling of the algae for final disposal, it is necessary to dewater so that the solids concentration could be increased to at least 10 to 20 percent by weight. Pilot scale studies of vacuum filtration, centrifugation, and gravity filtration were reported as dewatering steps by Golueke and Oswald[3] and the California Department of Water Resources.[5]

Vacuum Filtration

Attempts to dewater an algal slurry with a vacuum filter were found to be unsuccessful by Golueke and Oswald[3] because of the inability to form a cake of sufficient thickness to permit its removal. The California Department of Water Resources[5] experimented with a continuous belt vacuum filter. It was found that at a belt speed of 2.9 ft/min and with a vacuum of 15 to 20 inches of mercury, the unit could produce sludge containing 18 to 25 percent solids and remove 90 to 95 percent of the influent suspensions. Average concentration of solids in the effluent was about 300 mg/1 which necessitated recycling of the effluent from the unit.

Centrifugation

Golueke and Oswald[3,6] reported on the results of dewatering algal slurry using four different centrifuges, namely, the Byrd solid bowl, the Tolhurst solid bowl, the De Laval, and the MercoBowl (Dorr-Oliver) centrifuges. Except for the Byrd centrifuge, excellent results were obtained. At a feed rate of 2 to 4 gpm with an initial solids concentration of about 1100 mg/1, the centrifuged slurry was found to have a solids concentration of about 12 percent. The percent removal was about 78 percent. The experience of the California Department of Water Resources in dewatering by centrifuges has been mentioned earlier.

Gravity Filtration

Conventional types of filter media such as those used in sludge dewatering, namely, nylon, wool felt, canvas, paper, and paper backed with sponge, were tried by Golueke and Oswald.[3] All media proved to be capable of retaining the algae and suspended solids contained in the algal slurry. Nylon filters were easy to clean and proved durable. Wool felt was an effective medium but the felt fibers became entangled in the algal cake. Consequently, it was not found suitable as a filter medium. All the industrial filter papers proved satisfactory.

In pilot scale studies by Golueke and Oswald,[3] algal slurry was dewatered on sand beds framed with boards and covered with an industrial grade filter paper. In these studies it was shown that at an initial slurry depth of 2 inches, the algal slurry could be dewatered and air dried on the paper to a 12 to 15 percent moisture content within 24 to 30 hours. The paper could be used repeatedly.

The process of dewatering algal slurry on sand beds by drainage and allowing it to dry by evaporation was found to be the cheapest means of dewatering and drying algal slurries.[3] In pilot plant studies the sand used had particle sizes such that all of it passed through a 50-mesh screen and all but 11 percent was retained on a 140-mesh screen. A slurry was applied to the bed at a depth of 4.5 to 5 inches. Spoilage was found to occur when the applied depth was greater than 5 inches. After 24 to 48 hours the dewatered material had a solids content of 7 to 10 percent. Five to seven days of drying were required to bring the moisture content down to 15 to 20 percent. When dried, the algae formed chips. Most of the sand adhering to the dried algal chips could be removed by sieving the flakes over a 1/16-inch mesh screen. Firmly attached sand constituted from 2 to 3 percent of the dry weight of algal chips. Golueke and Oswald[3] estimated that about 6400 square feet of drying bed per acre of pond (algal concentration 200 mg/l) would be required. Also, a loss of about 15 percent of the sand per year should be expected.

DISPOSAL OF HARVESTED ALGAE

Harvested algae must be disposed of ultimately in a manner which does not create nuisance conditions or health hazards. The California Department of Water Resources considered the following alternatives for the final disposal of harvested algae.

Animal Food Supplement

Recently, there has been interest in the possible uses of unicellular algae as a protein source, especially for livestock feeding. As reported by the California Department of Water Resources,[5] the North American Aviation Company, Hintz et al., Leveille et al., Foree and McCarty, and others have experimented with sewage grown algae as livestock feed. Their investigations indicate that algae can be used as a substitute for such protein supplements as soybean, cottonseed, or fish meal especially in poultry feeding. A lucrative and sustained market for algae as a food supplement is yet to develop in this country.

Soil Conditioner

The California Department of Water Resources is of the opinion that, because algal products have a higher nitrogen content than dried activated sludge, they may find a receptive market as a soil conditioner, particularly for lawn, golf greens, etc. Presence of various salts in the algal product combined with its slow rate of decomposition, make algae a desirable lawn conditioner.

Gas Production

Suggestions have been made that an algal product can be converted to usable energy through methane fermentation with subsequent use of the methane gas to provide heat and/or electric power.

SUMMARY

With exacting requirements for treated waste effluents, particularly with regard to the suspended solids, the problem of algal removal from oxidation ponds and lagoons has become increasingly important.

Uni-algal cells have been found to carry a negative charge in the pH range of 2 to 11. They possess high charge densities at pH of 2 and 11, and a very low negative charge density at a pH of around 7. The chemical precipitation of algae has been postulated to be due to charge neutralization, agglomoration, and sedimentation. Even in sand filtration, surface interaction between algae and sand particles was found to be more significant than physical straining.

The handling of algae, in the removal process, consists essentially of three steps, namely, concentration, dewatering, and drying. In the first step, concentration of algae in the pond effluent varying from 200 mg/l to 4000 mg/l is increased to 1 to 4 percent by weight. In the dewatering step, the concentration of algae is increased to 8 to 20 percent; and in the final step it is increased to 85 to 90 percent.

Chemical coagulants, primarily cationic polymers, lime, alum, and ferric salts are effective in bringing about the coagulation and sedimentation of algal cells. Addition of small quantities of ferric salts either to the algal growth ponds or in the coagulation step, along with the primary coagulants like lime, alum, and cationic polymers, greatly enhanced the removal efficiency at much lower dosage rates of the primary coagulants compared with results for the primary coagulants alone.

Dewatering and drying of the algal slurry obtained from the concentration step could be most economically carried out by sand bed application. Vacuum filtration has been found to be only partially successful. High initial cost and recurring power costs render centrifugation only marginally attractive.

Use of sewage-grown algae as livestock feed and particularly as poultry feed appears to be promising, but a market has yet to develop. Use as soil conditioner, particularly for lawns, has been suggested. Anaerobic digestion, land fill, and other conventional methods of solids disposal from municipal waste treatment plants should be explored.

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