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Sewage Treatment in High Rate Oxidation Ponds under Australian Conditions

by

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ALGAL-BACTERIAL SYMBIOSIS IN HIGH RATE PONDS AS A METHOD OF TREATING SETTLED SEWAGE UNDER AUSTRALIAN CONDITIONS

- by -

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Preface.

The work reported in this document was sponsored by the Water Research Foundation of Australia and was carried out by members of the Public Health Engineering Section of the Department of Water Engineering of the School of Civil Engineering.

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SUMMARY

This report describes the reduction in the level of pollution in settled sewage by the natural process of algal-bacterial symbiosis in an open pond. The operating experience with a pilot plant pond using Sydney sewage at the Fairfield Sewage Treatment Works of the Metropolitan Water Sewerage and Drainage Board is also described. The results clearly showed that the same high rate of purification as obtained with similar units in the United States could be expected under local conditions in full scale plants. The widespread application of the process is restricted by the problem of separating the algae produced from the treated water flowing from a continuously operating unit. Methods of separation are described and their cost and applicability discussed.

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LIST OF ABBREVIATIONS

gm.	gram
l.	litre
ml.	millilitre
ppm	parts per
pH	logarithm of the reciprocal of the hydrogen ion concentration.
D.O.	Dissolved oxygen concentration as mg/l.

B.O.D.	Biochemical oxygen Demand as mg/l at 20°C. for 5 days.
D	Detention period as days
d	depth in inches
d'	depth in centimeters
S	average visible sunlight energy per day as cal/cm^2/day
S'	average visible sunlight energy as cal/l/day
L_t	average influent sewage B.O.D.
C_c	algal cell material as mg/l
Y_c	yield of algal cell material mg/l-day.
R	degree of carbon reduction
p	oxygen production per gram of algal cell synthesis.
h	algae heat content in calories per mg.
E	actual photosynthetic efficiency
F_c	critical " "
P	oxygenation factor

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1. INTRODUCTION.

Sewage as collected from the various domestic, commercial and industrial discharges contains much higher levels of impurities than can be tolerated at the point of discharge of the system.

Domestic sewage is composed of human excreta, household wastes, detergents, silt and fats and greases, carried by water from the community water supply system.

Although 99.9% of domestic sewage is water, treatment of the waste materials it contains to reduce the level of pollution that would otherwise occur in the region of the disposal area, presents a problem of considerable magnitude to many communities. Despite the fact that the quantity of the suspended and dissolved solids in the dewage is small, they can be the agents or carriers of disease, polluted water bodies and aesthetically undesirable odours if no treatment is carried out. (1)

Sewage Treatment Processes.

Raw Sewage is the term applied to the sewage as collected from the various outlets before treatment; it is first screened to remove large particles, passed through a grit chamber to remove heavy gritty material and then to a large settling tank, to separate the bulk of the finely dispersed solids from the liquid. The liquid overflow discharged from the settling tank usually requires biochemical treatment before it can be discharged. After leaving the settling tank, the treatment of the effluent or liquid stream takes a different course than that of the solids which were settled out. Since the solids which have been settled out are usually less than one per cent of the total volume of material entering the sedimentation tank, the treatment of the liquid overflow from the sedimentation tank is the major treatment in reducing the concentration of material present to a satisfactory level for discharge. This effluent from the primary sedimentation or settling tank is known as settled sewage. One of the methods used to treat settled sewage is by holding it for several days in open lagoons or oxidation ponds. Some of the oxygen for the organic decomposition is supplied by the atmosphere above the free surface of the pond. However, the bulk of the oxygen requirements are supplied by algae which grow in the pond. These algae, through their metabolism release additional oxygen for the decomposition process. As bacteria present in the settled sewage take part in the oxidation operation, the term symbiosis is applied to the process because of the symbiotic association of the two organisms, namely algae and bacteria. It has been found that in hot dry climates, algae in such ponds can supply in excess of 75 lbs. of oxygen per acre per day. This method of open ponding was accidentally discovered at the beginning of this century. Since that time more efficient designs have been used and the process has been studied and more closely defined. The algae, a form of green microscopic plant life, exist in the ponds in great numbers and perform an essential function in the breaking down of the organics in the sewage, as the bacteria, a natural component of sewage, use the by-products of the algae to purify the sewage. The bacteria in turn release by-products which are used by the algae. This interaction is known as the algal-bacterial symbiosis of oxidation ponds.

The process of algal-bacterial symbiosis for treating sewage has been extensively developed in laboratory experiments at the University of California, Berkeley, California, U.S.A. The principal investigators, H.B. Gotaas, W.J. Oswald, C.O. Golueke, H.F. Ludwig and B. Lynch of the Institute of Engineering Research, analysed the varying factors such as light and temperature which affect the process in a laboratory and then transferred their investigations to pilot tank experiments and after these experiments enunciated formulae for the design of large scale tanks. Their research has shown this method to be more effective and less expensive than other accepted methods of treatment. The value of the method depends on the profitable and useful disposal of the algae and also on its initial low cost, as described by Oswald et al. (2, 3).

The Micro-Organisms of Sewage.

The bacteria normally found in sewage may be classified into three groups according to their affinity to free oxygen in the substrate. Under the influence of enzymes, the bacteria absorb the organics and release by-products which are characteristic of the individual species of bacteria. In this way the organics are said to be broken down or oxidised. There are two main types of oxidation - (a) the obligate aeroces carry out the aerobic oxidation while (b) the obligate anaerobic bacteria carry out the anaerobic reaction. Facultative anaerobic bacteria can carry out either oxidation process. The anaerobic oxidation is usually accompanied by offensive odours caused by release of hydrogen sulphide and creates a condition which is more often referred to as septic.

The algae which are found in the oxidation pond are classified as microscopic green plants as they utilize sunlight as a source of energy. The algae synthesise carbohydrates through the use of sunlight, ammonia and carbon dioxide. This synthesis is referred to as photosynthesis, and the natural by-product of this reaction is free oxygen. The most common genera found in sewage are the *Chlorella*, *Scenedesmus*, *Euglena* and *Chlamydomonas*, which are shown in Figure 1. (4,5). Other forms of life, fungi, and protozoa are also found in sewage and are used in sewage treatment processes to ingest the bacteria and algae.

Sewage Oxidation Ponds.

Many terms have been used to describe the various types of oxidation ponds. These have included sewage lagoons, sewage stabilization ponds, anaerobic ponds, aerobic ponds and photosynthetic ponds. It is considered best to classify oxidation ponds according to the type of bacteria which inhabit their waters. These three types of ponds are aerobic, facultative and anaerobic. (6).

1. The anaerobic pond functions through the action of obligate anaerobes and facultative anaerobes and contains no free Oxygen. As described by Parker, (7) its main purpose is to act as a settling basin in which the heavier particles are settled out and later removed to be dried by the sun. The anaerobic pond is heavily loaded as it receives raw sewage which has had no prior treatment. As shown in Table 1 it is small in area, usually under one acre, up to ten feet in depth. The loading for this type of pond is high - 500 lb B.O.D./acre/day. In this type of pond the dissolved oxygen which might be absorbed from the atmosphere is quickly used up by the facultative anaerobes in decomposing the sewage. The pond then becomes septic, anaerobic and sometimes foul-smelling due to the anaerobic bacteria giving off hydrogen sulphide. The anaerobic pond is used where land costs are high. Sewage thus treated is further treated by facultative or aerobic ponds.

2. The facultative pond is the most commonly used and the one most often described in the literature, references (8 to 16). Aerobic decomposition is carried out in the supernatant layers of this type of pond by obligate aerobes and facultative anaerobes. Towards the

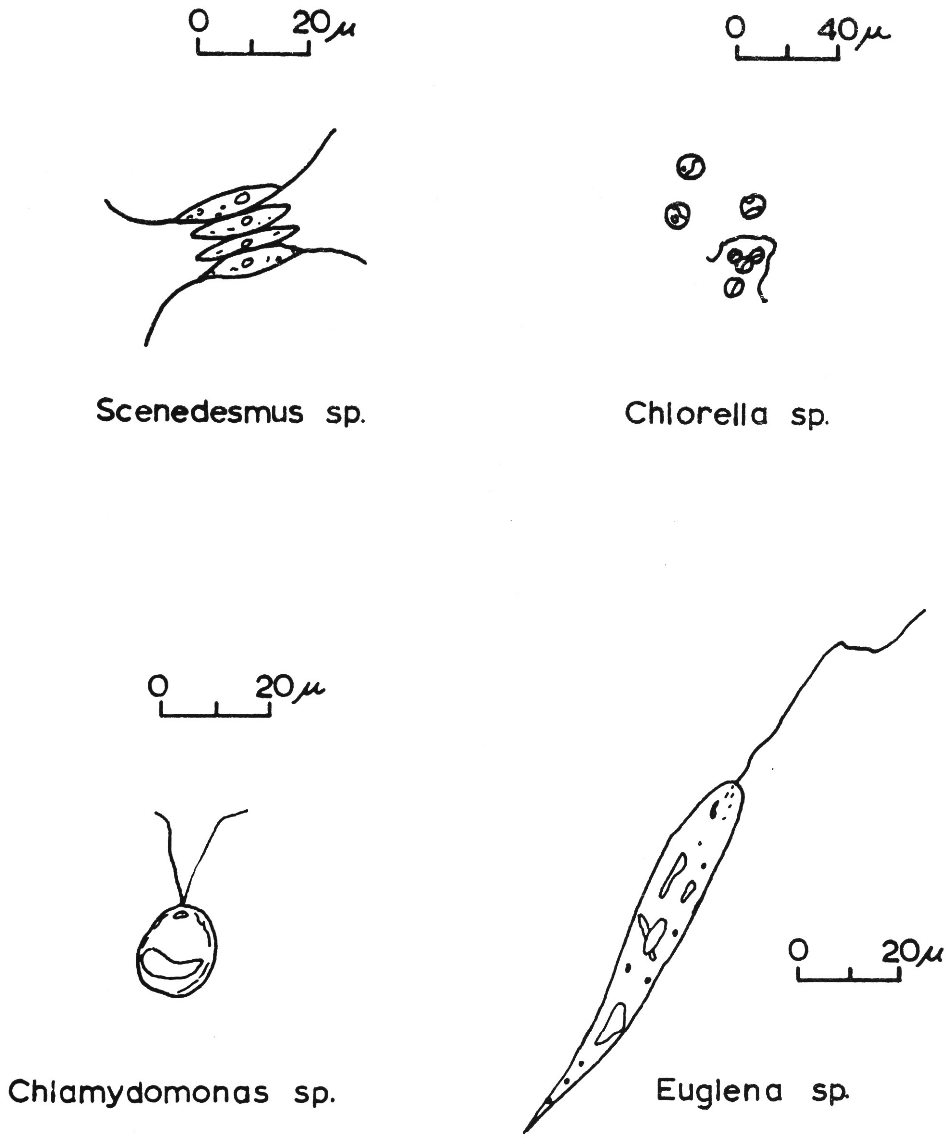


FIG. 1. ALGAE, COMMONLY FOUND IN SEWAGE OXIDATION PONDS.

bottom, the conditions are anaerobic as the heavier particles tend to settle out to the bottom. The facultative anaerobes and the obligate anaerobes carry out anaerobic oxidation at these depths. The surface area of these ponds varies from one to ten acres depending on bank erosion due to wind action. The depths usually used in design range from three to five feet. The effluent from such a pond is rarely above 50 ppm B.O.D. and usually high in algae content.

3. The high rate aerobic pond has been developed as a result of refining the usual facultative pond by reducing the depth and detention period. (17). The range of depths and detention periods found to be most efficient in reduction of B.O.D. and production of algal cell material is between two to sixteen inches and one to ten days respectively. In this way the high rate aerobic pond can handle loadings which far exceed those possible with the facultative type. However, the high rate aerobic pond must be carefully controlled and artificial mixing employed. The bacteria which exist in this type of pond are solely obligate aerobes and facultative anaerobes. It was this type of pond which the Water Research Foundation of Australia undertook to study as a possible means of sewage treatment in Australia.

A comparison of oxidation pond types under normal operating conditions is shown in Table 1.

TABLE 1

Classification of Oxidation Ponds Under Normal Operating Conditions.

Oxidation Pond Type	Other Systems of Nomenclature	Depth	Detention Period Days	Maximum Organic Loading lb/BOD/acre/day	pH	Light	Oxygen mg/ml
Anaerobic	Sewage Lagoon Stabilization Pond Sewage Pond Oxidation Pond	5-12 ft.	1-20 days	5000	5 to 7.5	Not req'd	None
Facultative	Sewage Lagoon Stabilization Pond Sewage Pond Photosynthetic Pond Oxidation Pond	3-5 ft.	20 days to 6 mths or effluent removal by evaporation	150	6 to 11.5	Req'd	0.24
Aerobic High Rate Pond	Photosynthetic Pond Oxidation Pond	2-24 ins.	1-10 days	500	6 to 11.5	Req'd	0-33

Alga-Bacterial Symbiosis in the High Rate Aerobic Pond.

The biological life and interaction between the various forms of life in the high rate pond are highly complex. In order to gain some knowledge of the processes within the pond, an understanding of the interaction of the biota is required.

Figure 2 illustrates in simplified form, the interaction between the algae existing in the pond and the bacteria decomposing its sewage. The settled sewage entering the pond contains many nutrients which are detained in the pond for an optimum length of time in order that the bacteria can metabolize making use of the nutrients. The by-products of the bacterial metabolism, ammonia, sulphates, phosphates and carbon dioxide are assimilated into algal cell material. (18, 19). Some of the oxygen and carbon dioxide escape to the atmosphere as they exist in the gaseous form in the pond. One of the more pronounced effects which the algal growth has on the pond is the rise in pH as free carbon dioxide is utilized by the algae.

The two components resulting from natural sedimentation of treated sewage are the sludge and the liquid effluent. Some more stable compounds which have been broken down into their more elemental forms are taken from the pond with the liquid effluent as humus. The proportion of humus to the liquid effluent is very small. The liquid effluent is composed of stable dissolved organic and inorganic compounds, and algal and bacterial cells. The effluent, having had the algal cells removed is very low in B.O.D. and suitable for discharge in most cases.

In order to illustrate the basic reactions which are included in the algal-bacterial symbiosis, the following reversible reaction has been set up by Gotaas et al (20),

$$CO_2 + H_2O \underset{\text{bacteria}}{\overset{\text{Algae + light}}{\rightleftharpoons}} \underset{\text{cell material}}{(CH_20) + 0_2}$$

As the amount of oxygen which can be absorbed by the pond from the atmosphere is limited by the low solubility which oxygen has in water, the bulk of the oxygen which is required by the bacterial oxidation process is supplied by the algal photosynthesis. This must be produced at a high enough rate to satisfy the demand of the bacteria in oxidising the substrate which is represented by (CH_20) when the reaction proceeds from right to left. In the photosynthetic reaction (CH_20) represents the living algal cells. The light which falls on the algal cells supplies the energy required by the reaction. The chlorophyll which is a component of the green algal cell is capable of utilizing light energy in aid of the reaction which produces oxygen which acts as the hydrogen acceptor for continued bacterial oxidation of the sewage substrate.

11. HIGH RATE POND OPERATION STUDIES

Pilot Plant Investigations at Richmond, California, U.S.A.

Work carried out at the University of California between 1953 and 1956 represents the most comprehensive study of high rate pond operation to be found in the literature. The work was performed by W.J. Oswald, H.B. Gotaas, C.G. Golueke, R.J. Hee, and E.L. Lee.

The project was carried out in three phases, designated as Pilot Plant 1, Pilot Plant 11, and Pilot Plant 111. The results are fully described in Progress Report No. 8 "Studies of Photosynthetic Oxygenation" (17).

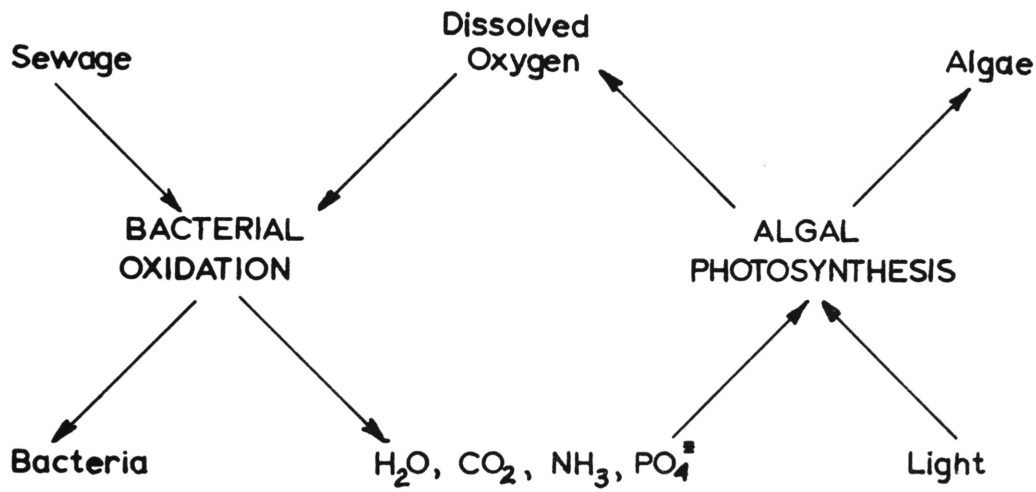


FIG. 2. ALGAL-BACTERIAL SYMBIOSIS.

The Pilot Plants each consisted of one or more ponds, constructed above the ground level. Each pilot plant represented an improvement in techniques and equipment over its predecessor.

Pilot Plant 1 studies were undertaken to determine whether algal-bacterial symbiosis out in the open, would be similar to the symbiosis studied in Laboratory investigations as reported in references (20 to 25). The single pond used for this phase was 80 feet in length, 3½ feet in width, and had a maximum depth of 3½ feet.

Pilot Plant 11 experiments were carried out using the pond built for Pilot Plant 1 as a control pond, and a second pond which was 14 feet by 65 feet having a maximum depth of two feet. Pilot Plant 11 was used as a basis for processing data to correct for variations in uncontrollable parameters such as influent sewage strength and solar radiation. Variations in depth, detention period and recirculation rate were made to determine their physical and chemical effect on the contents of the ponds. Sludge deposition was studied over the range of parameters. B.O.D. removal was determined as a function of loading and oxygenation factors.

Pilot Plant 111 was designed to determine the combined influence of depth, detention period, recirculation and mixing rates on algal production and sewage purification. The data obtained was to be analysed to establish design criteria for future ponds. Three ponds were built and designated A, B, and C. Each pond was 32 feet in length and eleven feet in width. The width varied as the sides were sloped. The minimum width at the bottom was five feet, the maximum depth was 2 feet 2½ inches.

In the operation of the ponds in the studies, the recirculation systems were similar in all cases, drawing from the effluent end of the pond and recirculating it into the influent end. Mixing systems employed were as follows:-

1. Pilot Plant 1 - manual stirring with a broom for ten minutes per day in all experiments.

2. Pilot Plant 11 - Three submersible pumps which re-distributed the ponds' waters through vertical jets on the bottom of the ponds were used.

3. Pilot Plant 111 - The mixing system consisted of two submersible 50 US gpm pumps in each pond.

Table 2 lists the ranges of values for independent variables used in the three pilot plant studies.

TABLE 2

Range of Independent Variables studied in Californian High Rate Ponds.

Variables	Pilot Plant		
	1	11	111
Depths (inches)	2 - 18	4 - 16	4 - 24
Detention Periods (days)	0.7 - 7	1 - 4	1 - 7
Recirculation Rate (Pond Volume per day)	2	0.5 - 2	0 - 2
Mixing Rate (min. /day)	10		
(U.S. gal. /Min.)		12-52.7	
(min. /hour).			0 - 24

Evaluation of Pond Performance

The values of the parameters measured during the pond operation have been used to determine transition levels and other important information for design purposes (21, 26). The following were evaluated:

(a) depth of light extinction,

(b) depth to which saturation light may reach,

(c) depth to which compensating light may reach,

(d) oxygen production per unit weight of algal cell growth

(e) degree of carbon reduction,

(f) heat content of the algal cell material,

(g) stability index,

(h) stabilization factor,

(i) hydraulic loading factor,

(j) oxygenation factor.

The synthesis of algal cell material is described in a publication by Oswald and Gotaas (17). On the basis of the Pilot Plant 1 studies at a depth of 2 inches and detention period of 0.75 days they estimated the following equation for algal synthesis -

$$NH_4^+ + 6.9\ CO_2 + 5.3\ H_20 = C_{6.9}H_{13.6}0_{2.8}N + 8.7\ 0_2 + H^+$$

This equation enables calculation of the oxygen produced per unit weight of cell material, p = 1.78 in this case.

The degree of carbon reduction, R, as derived by Spoehr and Milner (27) is given by:

$$R = \frac{(\%C \times 2.66) + (\%H \times 7.94) - (\%O)}{3.989} \qquad \ldots\ldots\ldots\ldots (1)$$

The cell heat content, h, per unit weight of algae produced is given by:

$$h = \frac{R}{7.89} + 0.4 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From the First Law of Thermodynamics equation (3) can be obtained:

$$h\ Y_c = S' F \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where Y_c = $\frac{\text{yield of algal cell material}}{\text{detention period}}$ = $\frac{C}{D}c$

S' = quantity of available solar energy in calories per litre per day

F = fraction of available solar energy utilised

C_c = algal cell material produced mg/l

The oxygenation factor, P, represents the degree to which the photosynthetic activity has met the influent oxygen demand and can be calculated from:

$$P = \frac{F}{F_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where $F_c = 0.94\ \frac{L_t}{S} \cdot \frac{d}{D}$ when h = 6 calories per mg.

L_t = B.O.D. exerted at any time t

S = available solar energy in calories per sq. cm. per day

d = depth of pond in inches

F_c = critical efficiency which must be achieved if the total oxygen demand is to be met through photosynthesis.

The stability index S is defined as the ratio of the B.O.D. to volatiles. While the stabilization factor $\triangle$ S is the difference between the stability index ratios of the influent and effluent of the pond.

Pond Operation

(a) Algal Species

The most common genera observed were *Chlorella*, *Scenedesmus*, *Chlamydomonas* and *Euglena*. Pilot Plant 1 results indicated that the population densities of the various species were dependent upon operating conditions. Pilot Plant 11 indicated a slow seasonal change, with Chlorella and Scenedesmus being in the majority, (17).

(b) Algal Counts

Algal counts were performed on all pilot plant tests. Pilot Plant 1 observations indicated that the total algal count increased with increasing detention period and decreased with increasing depth. Pilot Plant 11 studies showed similar results up to a detention period of four days. Pilot Plant 111 studies showed similar results, there being an average increase of 0.5×10^6 cells per ml. at a one day detention period to a count of 3×10^6 cells per ml. at a seven days detention period. An average of 3.0×10^6 cells per ml. were observed at a depth of four inches and decreased consistently down to a count of 1.5×10^6 cells per ml. at a depth of fourteen inches. There was no change in the range of cell counts over the range 14 to 24 inches.

(c) Packed Volume

The packed volume as determined by centrifuging at 500g for ten minutes was observed in all pilot plant experiments. The packed volume in the Pilot Plant 1 results decreased with decreasing detention period and increased with decrease in depth. These observations are in accord with the algal cell counts. The packed volume of the suspended matter in Pilot Plant 11 studies increased with increase in detention period. It was not ed that a peak of packed volume was reached at a depth of 12 inches. Pilot Plant 111 observations indicated a close correlation between cell count, suspended solids and the packed volume of the culture. Separation of the algal cells from the packed volumes was effected and the dry weight of the algal cells was determined. This dry weight increased with increase in detention up to seven days.

(d) Chlorophyll Content of the Algal Cells

It was observed in the Pilot Plant 1 studies that at short detention periods the chlorophyll content of the algal cell material was high. On a comparative basis, the total chlorophyll content of the water in the pond increased with detention period and decreased with an increase in depth. This was probably due to the age of the algal cells. Pilot Plant 111 results indicated that the total chlorophyll content of the waters in the pond decreased with depth from 3.2 ppm at 4 inches to 1.15 ppm at 19 inches.

(e) Total Suspended Solids

Suspended solids determinations were made on samples obtained from the supernatant pond waters after settling had occurred for a period of half an hour in an Imhoff cone. The Pilot Plant 111 results indicated that the solids content of the suspension increased with increase in detention period but decreased with an increase in depth. As these results are similar to the effect that depth and detention period have on the algal content, it is observed that the increase in suspended solids is largely due to increased algal content.

(f) Volatile Suspended Solids

The Pilot Plant 111 experiments indicated that upon increasing the detention period from one to seven days the volatiles in the suspended solids doubled. This was due principally to an increase in algal content which increased threefold over the increase in detention period. A decrease in depth brought about an increase in algal cells.

(g) Suspended Solids, Nitrogen Content.

The nitrogen content of the suspended solids is an important factor in evaluating the operation of the pond as it is a direct indication of the protein content of the suspended solids. It was observed that no mixing conditions in the pond were most effective in the production of protein. Turbidities and hence reduction of available light to the algal cells caused a reduction in protein content of the suspended solids. A maximum of protein production was observed at a detention period of four days. The nitrogen content obtained at shorter detention periods than four days remained low as the algal cells did not have time to make full use of the nitrogen available to them. At detention periods beyond four days the cells became old and no longer synthesised protein, resorting to the storage of non-nitrogenous substances. The limitation of nitrogen at greater detention periods may also have had an effect. A maximum nitrogen content was observed at a depth of fourteen inches. This was probably a result of the availability of light at greater depths and the excessive damaging light at lesser depths.

(h) Phosphorous Content of the Supernatant Liquid.

The effect of depths and detention periods on the phosphorous content of the centrifuged supernatant liquid showed an inverse relationship to algal content. It was observed in the Pilot Plant 111 studies that at depths below four inches phosphate starvation occurred in the algal cells. The only possible reason for the lack of available phosphate could have been the precipitation of phosphates as insoluble salts. This was most probably due to the high pH levels at the lower depths.

(i) Nitrogen in form of Ammonia

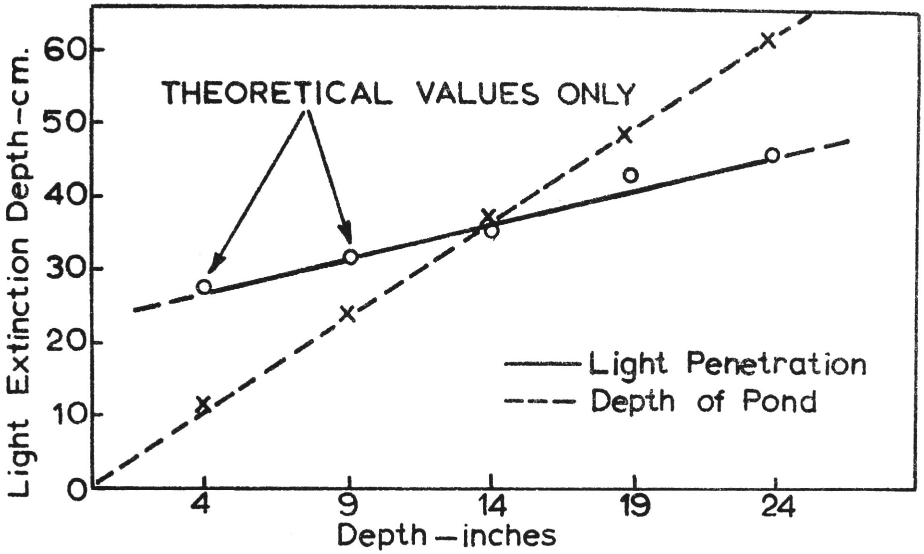
A study was made in each of the pilot plant tests to determine the nitrogen change in the pond over the several levels of independent parameters. The effect of algal growth was apparent in each of the studies as ammonia nitrogen is the principal source of nitrogen in algal synthesis. It has been suggested by Oswald et al. (17) that "the amount of NH_4^+ - N or NH_3 - N remaining in the supernatant liquid also may be indicative of the photosynthetic oxygenation process." An increase in detention period resulted in a definite decrease in the ammonia content of the supernatant liquid. Similarly an increase in depth resulted in an increase in NH_4 -N remaining.

(j) Light penetration.

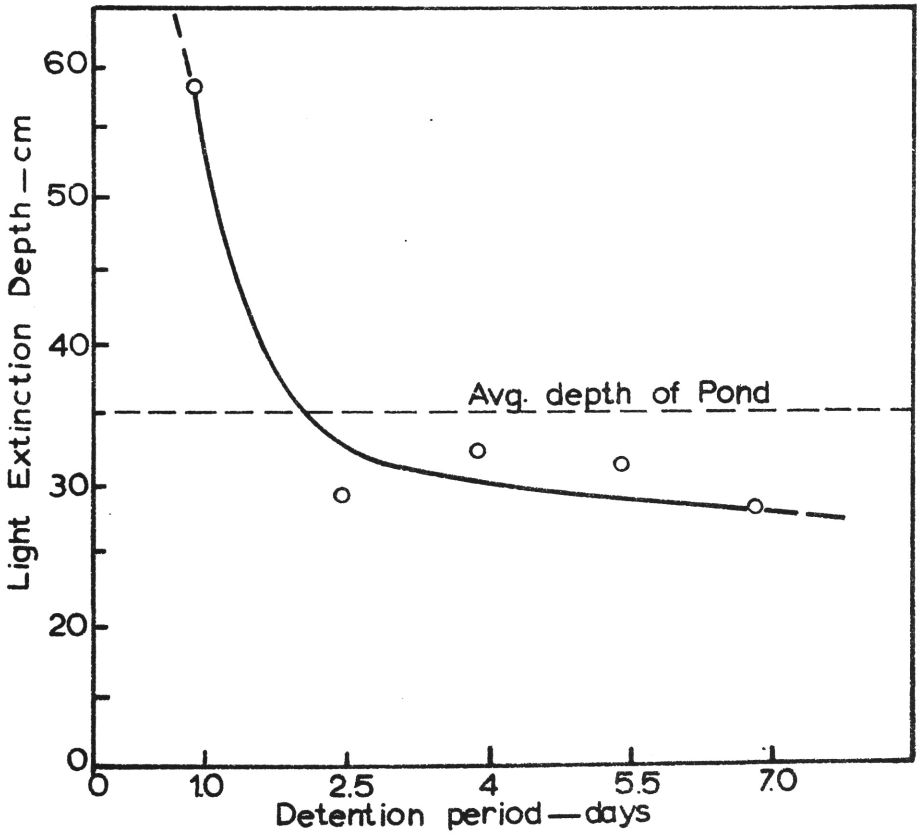
The light penetration was determined by measuring the depths at which saturation light intensity (400 foot candles), compensating intensity (30 foot candles) and light extinction occurred. The incident light was used as average daylight in all three studies. Figure 3 shows the observed variation in the total extinction depth through the variation of depths and detention times in Pilot Plant 111 studies. The effect of the increased turbidity at longer detention periods is evident. The influence of depth indicates the effect of turbidity due to algal cells.

(k) pH and Dissolved Oxygen.

pH and dissolved oxygen studies included measurements at 9 a.m. and 2 p.m. on every day of the tests in all pilot plants. Pilot Plant 11 included 24 hour studies of the parameters. Figures 4 and 5 show the average variation of pH and dissolved oxygen with depth and detention period for the Pilot Plant 111 studies. High pH values indicate increased algal activity in the uptake of carbon dioxide and production of algae. The dissolved oxygen curves indicate a levelling off after detention periods of four days. This is due to the supersaturation of oxygen reaching such high proportions that it is lost to the atmosphere. At a depth of fourteen inches the

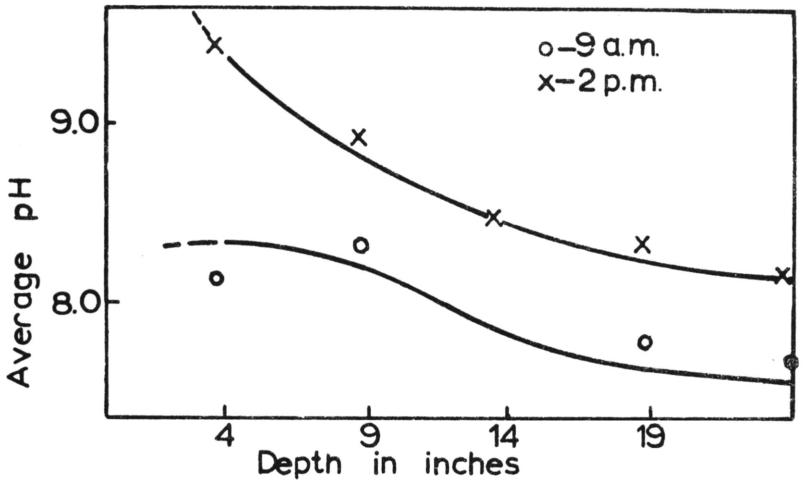


3 a. LIGHT EXTINCTION DEPTH VS. DEPTH.

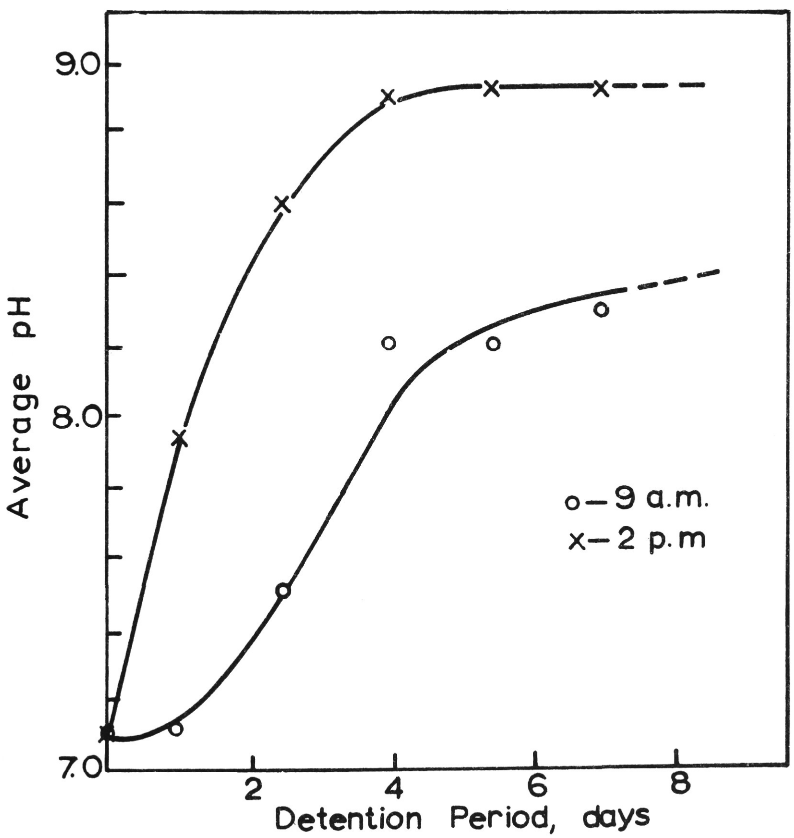


3 b. LIGHT EXTINCTION DEPTH VS. DETENTION PERIOD

FIG. 3. LIGHT EXTINCTION DEPTH VS. DEPTH AND DETENTION PERIOD, REPRODUCED FROM (17)

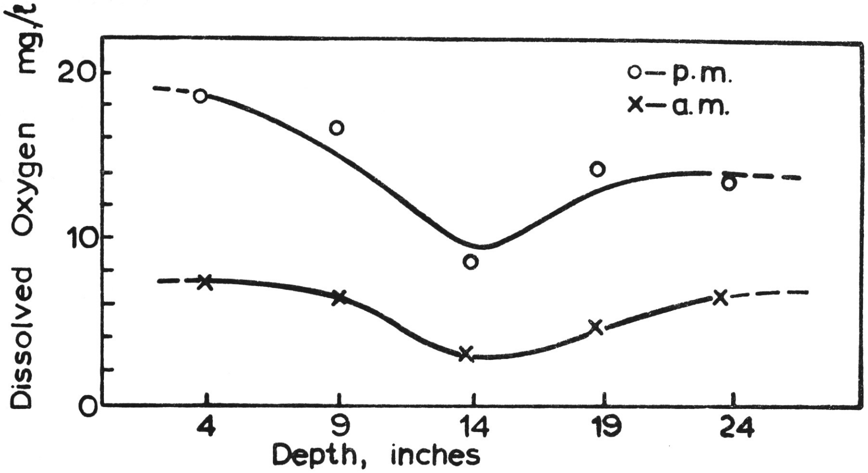


4 a. pH VS. DEPTH

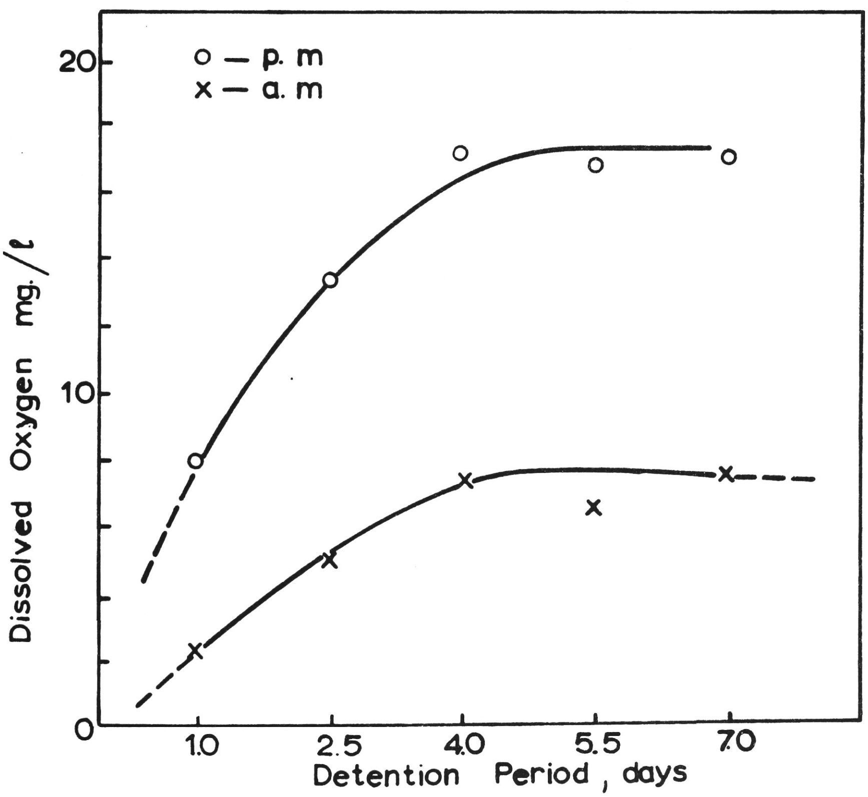


4 b. pH VS. DETENTION PERIOD

FIG. 4. pH VERSUS DEPTH AND DETENTION PERIOD, REPRODUCED FROM (17)



5a. DISSOLVED OXYGEN VS DEPTH



5 b DISSOLVED OXYGEN VS DETENTION PERIOD

FIG. 5 DISSOLVED OXYGEN VERSUS DEPTH AND DETENTION PERIOD, REPRODUCED FROM (17) the conditions favouring loss of oxygen were more extensive than those at 19 and 24 inch depths.

(l) B.O.D. Reduction

B.O.D. reduction and its dependence upon depth and detention period is best illustrated by Figure 6 which shows average B.O.D. removals in Pilot Plant 11. A definite peak indicates high reduction at three days detention. Pilot plant 111 studied B.O.D. removal in terms of stabilization factors and in the studies Pilot Plant 11 results were confirmed.

(m) Sludge Deposition.

Pilot Plant 11 included studies on sludge deposition which although not complete, results did suggest a pattern of slow sludge build-up. Due to the test programme undertaken, measurement of the sludge deposition at varying depths and detention periods was not practicable.

(n) Oxygenation Factor

Figure 7 shows the oxygenation factor F/F_c as plotted against Hydraulic Loading Factor as observed in the Pilot Plant 111 experiments, and reproduced from (17). As may be noted from the plot the oxygenation factor serves as a valuable indication of the performance of the pond. As the oxygen demand is met by photosynthetic activity at oxygenation factors greater than one, it is desirable to design ponds with factors above 1.5 and thus loading factors less than 3.5.

111. OPERATION OF HIGH RATE PONDS IN AUSTRALIA

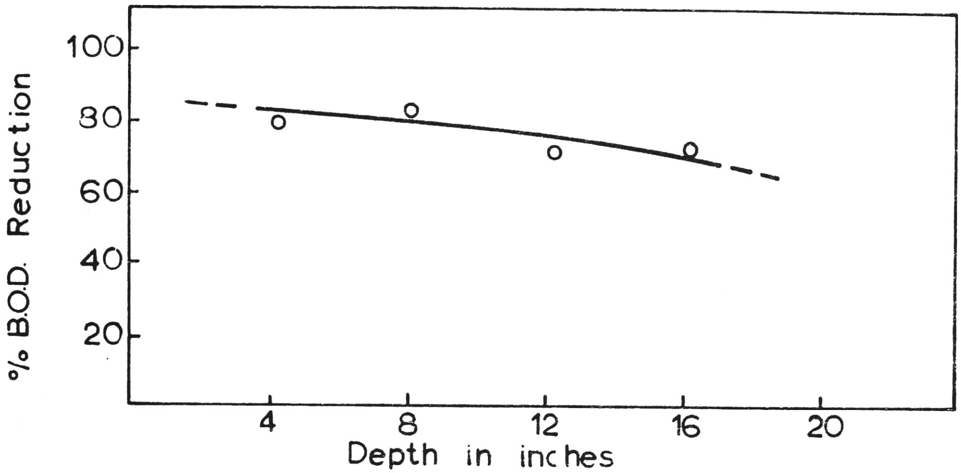
The use of high rate oxidation ponds in Australia has been confined to the work which was carried out by the Water Research Foundation between 1957 and 1962. The project was first proposed to the Water Research Foundation by Sir Phillip Baxter. The Foundation established a research fellowship for the purposes of the investigation which was entitled "The use of green algae as a method of sewage treatment". It was decided that the work in the project would be carried out by a full time research fellow under the direction of an advisory panel of experts consisting of Associate Professor P.W.S. Ryan, Professor F.W. Ayscough, Mr. D.K.B. Thistlethwayte and Professor B.J. Ralph. Mr. F.J. Gardner B.Sc. (Agriculture) was appointed as research fellow and commenced work in May 1957 and worked on the investigation until 1962.

The purpose of the Foundation's project was to carry out a study of the system used in California, under local conditions to -

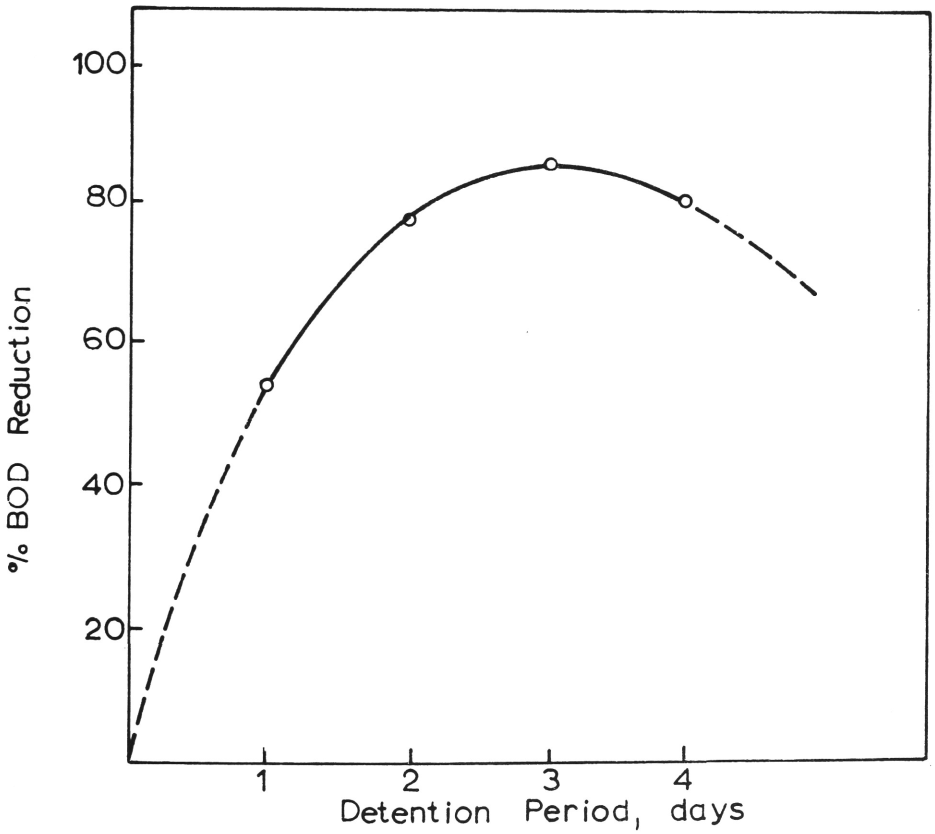
1. Determine whether such a system could be used successfully in Australia.
2. Compare the operation of a high rate pond in Australia to that in the United States and
3. Compare the high rate pond system of sewage treatment to other systems used locally.

Laboratory Investigations

Before undertaking the construction of the pilot plant pond, it was necessary to undertake laboratory experiments to determine whether sewage from which the bulk of the solid material had been removed by settling out, could be purified through the algal-bacterial symbiosis process. Two aspects were of importance



6a % B.O.D. REMOVAL VS. DEPTH



6b. % B.O.D. REMOVAL VS. DETENTION PERIOD

FIG. 6. % B.O.D. REMOVAL VERSUS DEPTH AND DETENTION. PERIOD, REPRODUCED FROM (17).

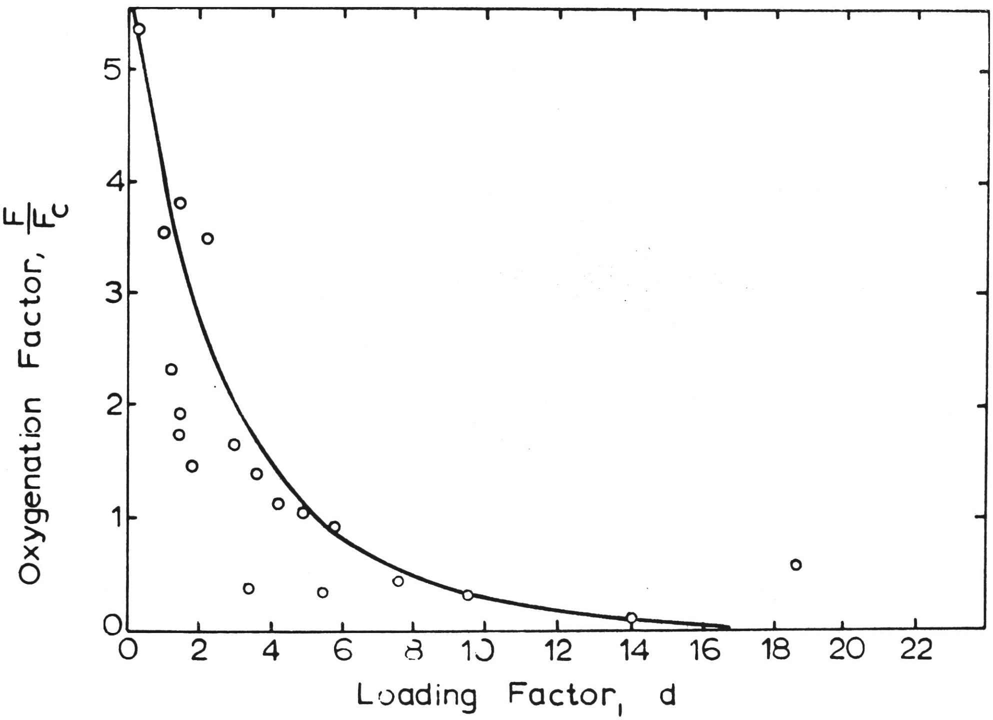


FIG. 7 OXYGENATION FACTOR VERSUS LOADING FACTOR, REPRODUCED FROM (17)

1) the purification achieved as measured by the B.O.D. reduction and,

2) the conditions under which algae could be maintained in such a pond.

In the experimental work, nine 300 ml. samples of settled sewage were placed in 1 litre capacity Erlenmeyer flasks and innoculated with a composite 50 ml. sample of algae.

The algae used for innoculation were collected at Fairfield on 31st July, 1957, from the grit chamber of the new works, from the oxidation ponds and some were scraped off stones from the biological filter.

A composite culture was added at 50 mls per 300 mls sewage. It was estimated that the algal composition was approximately: 50% Euglena, 40% Chlamydomonas, 5% Scenedesmus, 3% Chilodon, and also Chlorella 2%, Ankistrodesmus, Oscillatoria, Hormidium and a few blue-green algae like Aphanacapsa.

Six of the flasks were aerated using air which had first been filtered in an oil and water extract and then a cotton wool filter. All flasks were plugged with cotton wool and faced north in the laboratory with white paper on the south side to reflect light into the culture. Five of the flasks were fed daily with fresh sewage by first withdrawing 50 ml. of the contents of the flask and then adding 50 ml. of fresh sewage. Two of the flasks had 50 ml. removed daily, which was filtered and the filtrate, freed from the algae which were discarded, was returned to the flask. All flasks were innoculated on 31st July, 1957 and daily feeding and filtering, where applicable commenced on 7th August, 1957.

The arrangement used in the laboratory is shown in Figure 8. The results of the preliminary investigation are listed in Table 3.

Laboratory Observations.

pH measurements were made on a daily basis. For the aerated and stirred samples the pH varied between 7 and 8. The samples which were filtered and not stirred showed pH values between 6 and 7 as did the sample which was not stirred.

In most of the flasks a green solution was observed. Those samples which were not fed daily turned yellow indicating that the algae had died. These samples produced gas bubbles similar to anaerobic conditions. The unstirred sample was capable of producing enough oxygen to biodegrade the sewage, which was injected daily. This indicated that the algal-bacterial symbiosis occured in that sample. The experiments showed that a detention time of 5 days was adequate for algal production. It also showed that the algae would thrive under conditions described by Table 3. It was noted that the genera of algae observed in the preliminary experiments differed from those observed in the Californian investigations.

In view of the above observations, it was decided by the Advisory Panel to proceed with the construction of a pond at the Fairfield Sewage Treatment Plant of the Metropolitan Water Sewerage and Drainage Board.

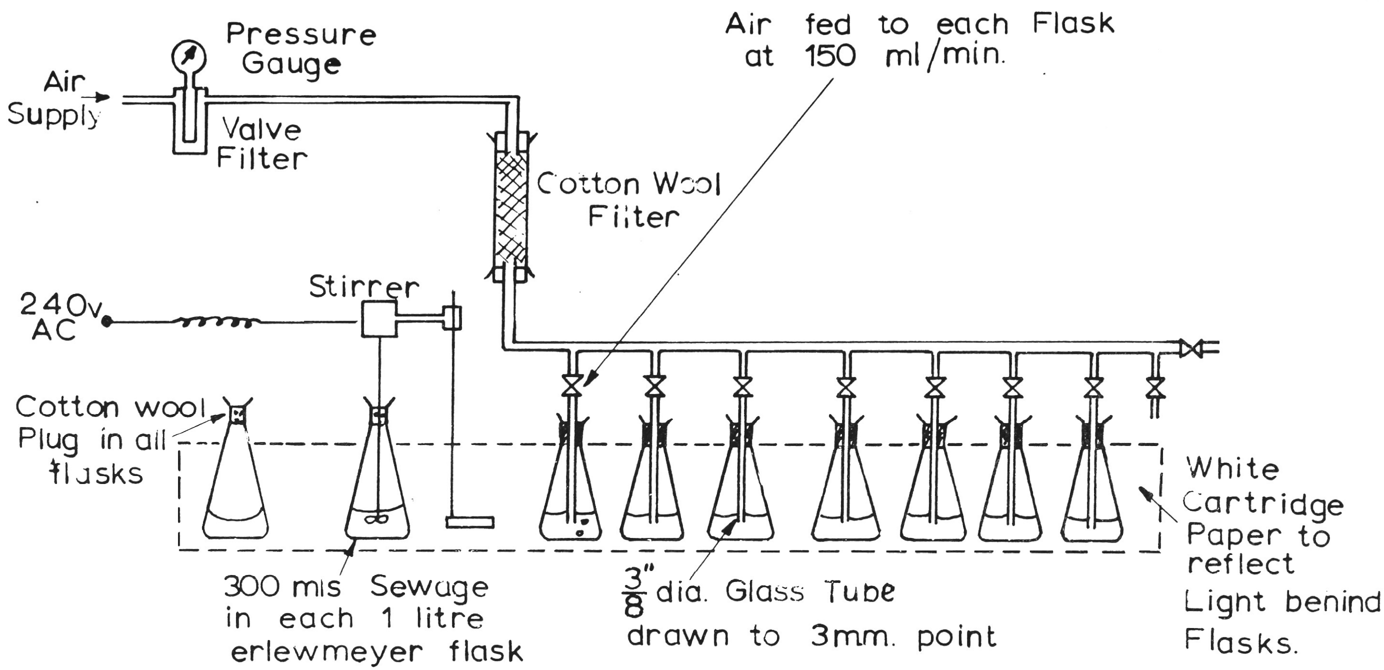


FIG. 8. EXPERIMENTAL ARRANGEMENT USED IN LABORATORY TESTS

TABLE 3

LABORATORY INVESTIGATIONS AND OBSERVATIONS

Flask	Sewage	Aerated	Fed Daily	Filtered Daily	Algae Developed
1	Domestic	Yes	Yes	No	2% Chlamydomona 10% Scenedesmus 80% Chlorella 3% Cyclidium
2	Industrial	Yes	Yes	No	Amoeba, Colpoda Nitzschia, Navicula, Chodatella, Ulothrix Physomonas
3	Domestic	Yes	No	Yes	As for 1 and 2 but few in number
4	Industrial	Yes	No	Yes	and dying
5	Domestic	Yes	4% CO_2	No	Chlorella, Scenedesmus (abundant) Coelastrum
6	Industrial	Yes	4% CO_2	No	Amoeba Chodatella
7	Domestic	No	No	No	As for 1 and 2 but more
8	Industrial	No	No	No	Chlamydomonas
9	Industrial	No	Yes	No	Laboratory stirrer used. Top samples showed Chlamydomonas Bottom samples Chodatella, Aphanocapsa, Nephrocytium, Oscillatoria, Synedra, and Ocystis.

The Fairfield Pilot Plant (1957 to 1962)

Two designs for the pond were considered by the Advisory Panel. These were one circular, and one rectangular in shape. It was originally thought that the design of a circular pond would overcome the problem of shading. However, after further consideration by the Advisory Panel the circular design was rejected.

The pond, as shown in Figure 9, was designed in the form of a rectangular tank. It was 35 ft. 6 inches long by 11 ft. wide and 2 ft. deep for two thirds of its length. At the outlet end the last 8 feet sloped to 2 feet 6 inches deep in a U-shaped trough to provide an area for concentration and drainage. The walls were designed to be sloping, the bottom of the pond having a width of five feet. Both ends of the pond were vertical with a feed chamber 5 feet by 1 foot and an exit well 2 feet by 2 feet.

The tank was constructed of concrete dug into the ground with the top rim protruding 3 inches above the ground to prevent any flooding from the surrounding area.

The surface area of the pond was determined by the following formula,

$$A = 187.6 + 112.2\,d \qquad \ldots \quad (5)$$

where A is the area in square feet

and d is the depth in feet

The volume of the pond at the various depths was determined by

$$V = 187.6\,d + 56.2\,d^2 \qquad \ldots \quad (6)$$

where V is the volume in cubic feet

The detention period of a given flow into the pond at a given depth was:

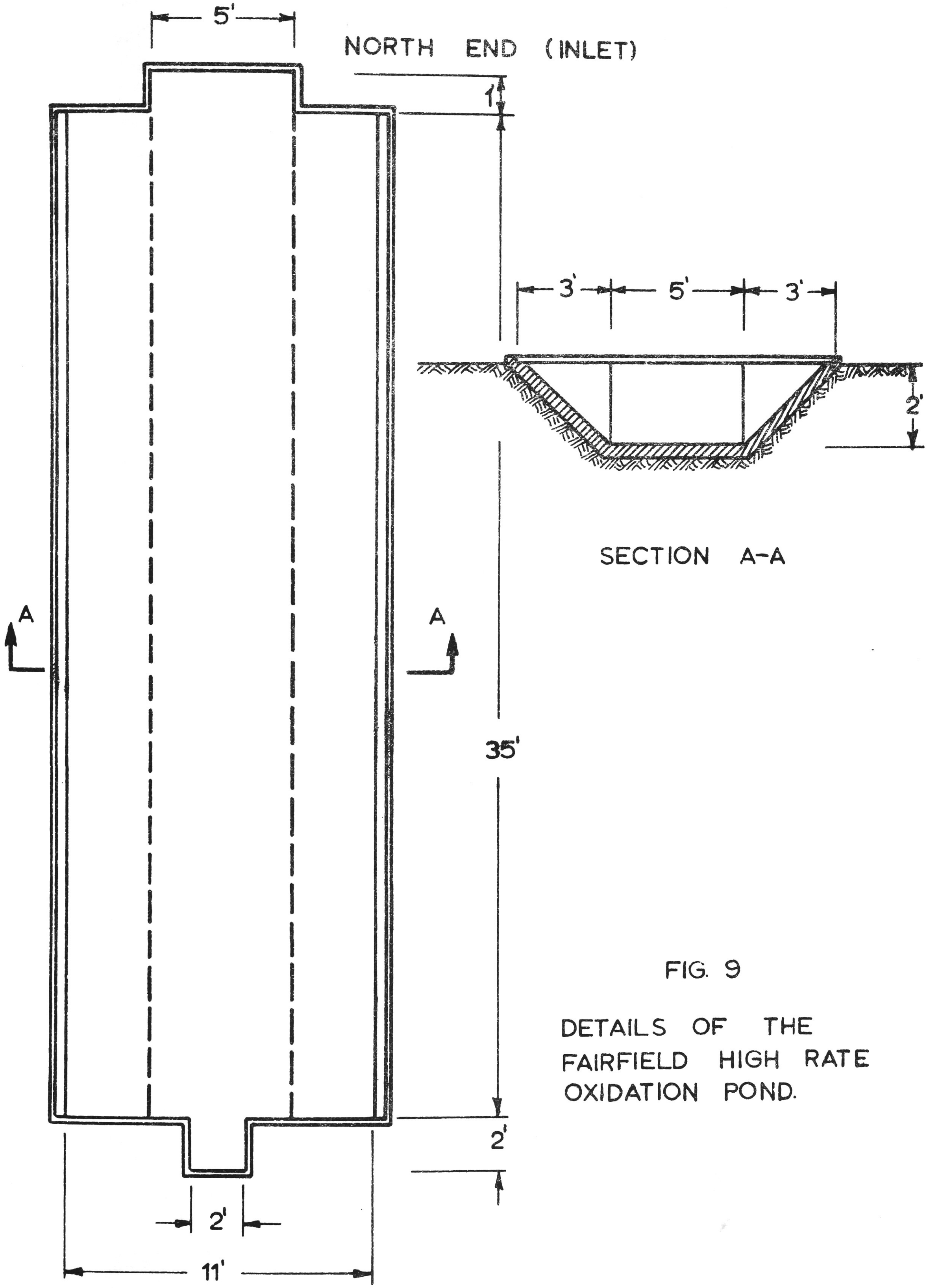


FIG. 9

DETAILS OF THE FAIRFIELD HIGH RATE OXIDATION POND.

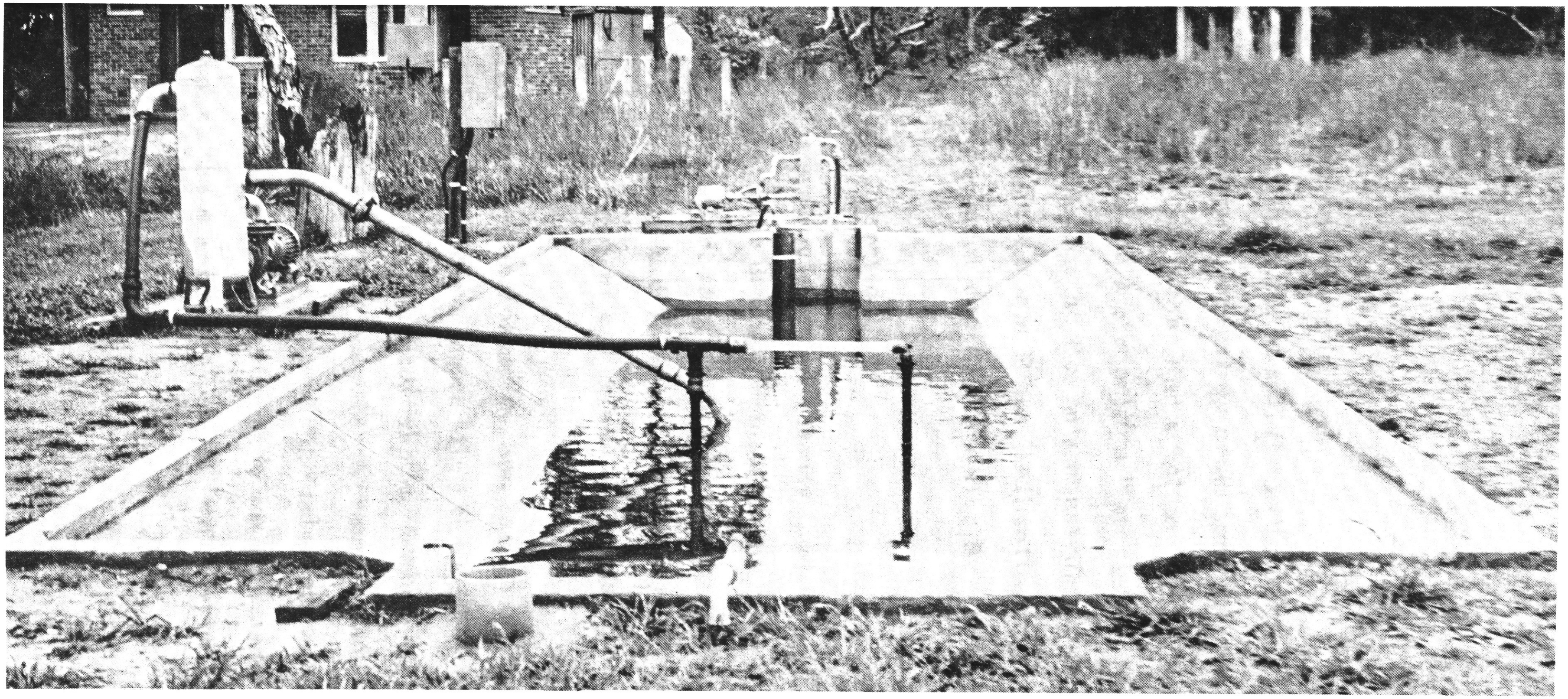


Figure 10. View of Pond looking south (1957 - 1962)
Approximately 10" of liquid lies in pond.

$$D = \frac{Q}{V} \qquad \ldots\ldots\ldots \qquad (7)$$

where Q = flow in cubic feet per day

and D = detention period in days

The capacity of the pond was 3,700 gallons when full to the ledge but under the normal operating conditions the water level did not exceed twenty one inches and a volume of 3,100 gallons.

Negotiations with the Metropolitan Water, Sewerage and Drainage Board resulted in the Board's constructing the pond at the Fairfield Sewage Treatment Plant. All influent, effluent and mixing facilities were provided by the Water Research Foundation grant.

Description of Pond Operation.

The settled sewage flowed by gravity from one of the treatment plant trickling filter dosing syphons through a 1 inch diameter pipe to the 4 foot long manifold resting on the bottom of the inlet end sump which had ¼ inch holes at 1 foot centres. There were no screens or seives at either end of the line, and no pumps were used.

Each drainpipe on the dosing syphon had an offtake 1 foot long with a stop-cock before a tee to allow the syphon to be flushed daily by the staff of the treatment works, and when necessary to clean the influent pipe. The flow rates were adjusted by hand by a plug cock with removable wrench at the inlet end sump. To check the rate of flow a stop cock and tee with plug were provided in order to bypass the manifold. The influent system is outlined in Figure 11 (a).

The effluent was discharged from the effluent pump through piping to a manhole on the bank of Orphan School Creek and thence through pumping station 123 back through the treatment works. It could also be pumped to a small laboratory when necessary and after the removal of algae could drain by gravity back to the manhole. The effluent pump was controlled by a float switch whose float was located in a stilling well 6" in diameter made of galvanized sheet. In this way an attempt to control the depth of the pond was employed. The effluent system is outlined in Figure 11 (b).

The mixing pump was controlled by a synchronous timer which switched on for six minutes every hour. The influent to the mixing pump was through a check valve intake located in the centre of the pond. The distribution of the mixing water was made through a network of pipes laid on the bottom of the pond having holes throughout their length to disperse and mix the liquid in the pond. The mixing system is outlined in Figure 11 (c).

The detention period was controlled only by the valve in the influent line. The depth of the pond was maintained between 16 and 18 inches. In some instances during the operation of the pond the gravity flow influent line became plugged and the depth was lowered below the 16 inch level by evaporation, and the detention time rose considerably above the intended period of five days.

Evaporation was taken into account during the course of the experiment and reached 1 to 1½ inches per week in summer and ½ inch per week in winter. Whenever evaporation exceeded the influent rate and the level in the pond decreased as a result, the liquid in the pond was replenished with tap water. The loss in

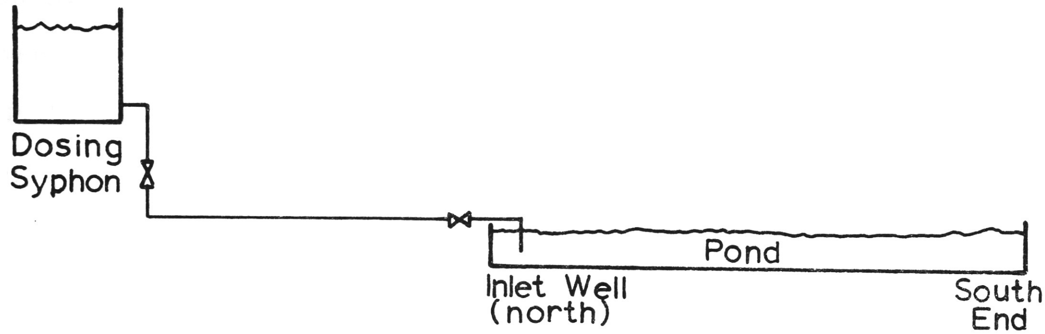


FIG. 11 (a) INFLUENT SYSTEM

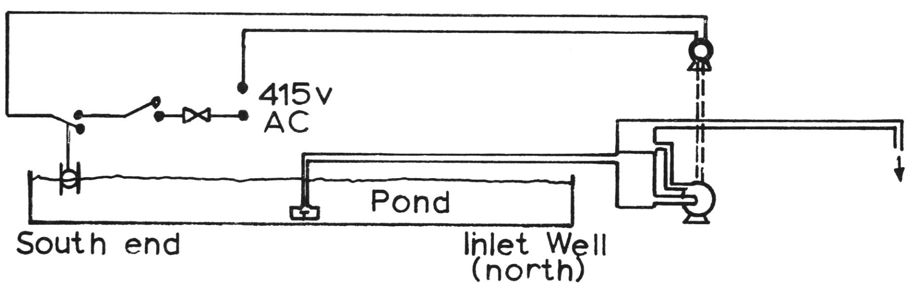


FIG. 11 (b) EFFLUENT SYSTEM

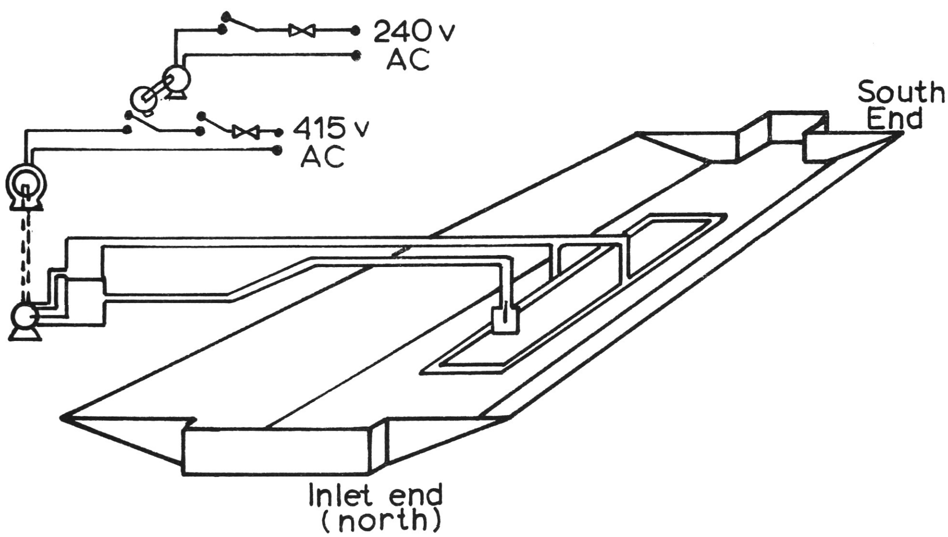


FIG. 11 (c) MIXING SYSTEM

FIG. 11. POND FLOW SYSTEMS (1957—1962)

detention time due to rainfall was particularly important during November and part of December in 1961 when at least sixteen inches of rain fell. No simple physical correction could be made for this situation.

The pond was put into operation in September, 1960. It was seeded with cultures of algae which were largely Chlorella and Scenedesmus in genera. Culture growth occurred within three weeks when algal counts were observed to be similar to those observed in the Californian ponds. With satisfactory culture growth attained, the influent line was then adjusted to maintain the correct detention period and the effluent float control was set to maintain the appropriate depth. Although the pond was mixed by hand, it became septic and anaerobic on several occasions. Installation of the mixing pump and its periodic operation solved this difficulty.

Observations

The Fairfield pilot plant was kept in continuous operation between October 1960 and February 1962. Observations were made on the waters in the pond on a weekly and sometimes fortnightly basis. The analyses of the waters in the pond included (a) colour, (b) odour, (c) dissolved oxygen, (d) pH, (e) packed centrifuged volume, (f) cells per millilitre, (g) temperature, (h) algal genera (i) influent B.O.D., (j) effluent B.O.D., (k) centrifuged effluent B.O.D., (l) total solids, (m) settled solids and (n) alkalinities. All analyses were performed according to "Standard Methods for the Examination of Water and Wastewater" (28).

These observations are set out in Tables 4, 5 and 6. The observations were made between 9 a.m. and 11 a.m. on the dates indicated. Explanations of the column headings in the tables are as follows.

(a) Table 4

Column 1 indicates the colour of the sample as withdrawn from the pond.

Column 2 describes the odour of the water in the pond, together with identification of H_2S gas if present.

Column 3 gives the dissolved oxygen content of the sample from the pond. The dissolved oxygen analyses were performed using the Azide-Al sterberg modification of the Winkler method (28).

Column 4 fives the pH of the sample. A pH comparator was used in these analyses.

Column 5 gives the volume of the compacted solids resulting from centrifuging operations. These observations are given as millilitres of packed sludge and algal cells per litre of pond water.

Column 6 is the total number of cells estimated from identification of organisms present in several squares of a haemocytometer under a microscope. They were observed as cells per millilitre of pond water.

Column 7 shows the temperature in degrees Centigrade of the air in the vicinity of the pond.

Column 8 records the weather in the vicinity of the pond on the date indicated and at the time of sampling and observing the pond.

(b) Table 5

This table lists the individual counts of different genera of algae and other organisms present. The cells counted under the heading "Others" include those whose population was very low. The percent quantity of each of the principal algae based on the total number counted is listed also.

(c) Table 6

Column 1 gives the temperature in degrees Centigrade at which the B.O.D. test was carried out together with the period of time between the two dissolved oxygen determinations. The reason for carrying out the test at 25^{o}C resulted from the lack of a suitable incubator at 20^{o}C with heating and cooling facilities. B.O.D. determinations made at 25^{o}C were made using a Warburg apparatus.

Column 2 gives the B.O.D. measured for the settled sewage - the influent to the pond.

Column 3 gives the B.O.D. measured from the effluent of the pond as sampled while the algae were still present in the sample.

Column 4 indicates the B.O.D. measured for the effluent after the algae had been centrifuged out.

Column 5 gives the percent B.O.D. reduction achieved in the pond measured as the difference between the influent B.O.D. (Column 2) and the centrifuged effluent (Column 4) given both in ppm oxygen demand and % reduction.

Column 6 gives the value of the total solids as ppm by weight present in the effluent water.

Column 7 lists the settled solids as ppm by weight in the effluent water determined by decanting off the supernatant liquid from an Imhoff cone after settling had occurred.

Column 8 indicates the total alkalinity observed in the waters of the pond in ppm as calcium carbonate.

TABLE 4a OBSERVATIONS

Date 1960	Colour	Odour	Dissolved oxygen ppm.	pH	Centrif. Vol. ml/l	Cells per ml.	Temp °C	Weather	Comments
Sep. 5	grey brown	septic	0.0		4.13		19	fine warm	began seeding 2½% culture
Sep. 13	brownish green	rank			0.5			cloudy	growth fair
Sep. 20	light green	less odour			1.63		18	cloudy cool	
Sep. 23	bright green	none	15.5		2.1	1.7×10^6	16.8		
Sep. 27	bright green	none	12.5		2.35	2.4×10^6	19.4		
Sep. 28	bright green				2.98				
Oct. 4	bright green		14.3	9.2	4.25	9.1×10^6	17.4		
Oct. 7		H_2S identified	18.0	9.5	6.25		17.8	fine	evaporation high
Oct. 11	yellow green	H_2S identified	10.5	9.2	4.50		25.6	fine	120 gals. influent added
Oct. 14	medium green	slight H_2S and septic	14.6	9.4	2.0	3.7×10^6	26.0	hot fine	
Oct. 19	medium to dark green	none	19.7	9.2	2.5		18.8	cloudy wet	2 inches less replenished.

TABLE 4b OBSERVATIONS

Date 1960	Colour	Odour	Dissolved oxygen ppm.	pH	Centrif vol. ml/l	Cells per ml	Temp °C	Weather	Comments
Oct. 21	medium green	nil	34.5	9.4	3.5		17.4	cloudy wet	
Oct. 25	medium green	nil	1.4	8.0	2.25		18.8	cloudy wet	1½" rain 100 gallons influent added
Nov. 1	medium green	nil	10.4	7.2	1.5	1.41×10^6	23.2	warm	200 gallons influent added
Nov. 4	dark green	H_2S	23.9	9.2	1.0		21.4	cloudy cold	
Nov. 7	dark green	H_2S	23.9		1.75	4.1×10^6		fine	
Nov. 11			13.4					fine warm	
Dec. 7	bright green to black	septic	0.3					wet	
Dec. 13	bright green	stagnant			.5	$.48 \times 10^6$		wet cold	
Dec. 29	black green	H_2S			3.75			hot	

TABLE 4c OBSERVATIONS

Date 1961	Colour	Odour	Dissolved Oxygen ppm	pH	Centrif Vol. ml/l	Cells per ml.	Temp ^{o}C	Weather	Comments
Jan. 13	black green	dank			3.25			hot	
Feb. 7	medium green	fresh	18					fine hot	
Mar. 7	dark green				1.5				
Mar. 20	dark green								
Mar. 22	dark green					$3.1x10^6$			
Apr. 18					2.5			cloudy	
Apr. 27	dark green				4.5	$1.15x10^6$		cloudy	
Jun. 6	dark green	fresh	12.8		1.7		12	fine	200 gallons
Jun. 22	dark green			8.8	2.0		12		
Jun. 26			15.8	8.2			11	fine	
Jun. 29			15.0	8.1	2.5		11		
Jul. 6				8.6	2.5		11	fine windy	
Jul. 13	dark green			8.8	2.25		12		243 galls. infiltrate added in three days

TABLE 4d OBSERVATIONS

Date 1961	Colour	Odour	Dissolved Oxygen ppm	pH	Centrif Vol ml/l	Cells per ml.	Temp °C	Weather	Comments
Jul. 20			13.3						
Jul. 24					2.5	4.36×10^{6}			
Aug. 10	very dark green				2.18				
Aug. 17	very dark green	fresh							no influent or effluent
Aug. 24				8.6	4.5	4.85×10^{6}			
Sep. 28			28	10.0			25	no rain	
Oct. 12			34.0	8.8	3.75	2.55×10^{6}	25	rain	0.129 ins.
Oct. 19			6.5		3.0			rain	0.48 ins.
Oct. 26	black	septic	2.6	7.4	3.75			rain	0.42 ins.
Nov. 2			0.1	7.4	11.3	8.5×10^{6}	25		
Nov. 11			17.0	7.2	3.5	3.35×10^{6}	25		
Nov. 23			7.6	7.6	2.25	2.18×10^{6}	21	rain	1.138 ins.
Nov. 30			12.1		2.5	1.5×10^{6}	25	rain	0.235 ins.
Dec. 14			29.6	7.9		4	25	rain	0.25 ins.
Dec. 21							27	rain	0.202 ins.

TABLE 4e OBSERVATIONS

Date	Colour	Odour	Dissolved Oxygen ppm	pH	Centrif Vol. ml/l	Cells per ml.	Temp ^{o}C	Weather	Comments
Dec. 28							25	rain	0.198 inches
1962 Jan. 4								rain	0.025 inches
Jan. 11								rain	0.319 inches
Jan. 18							26	rain	0.223 inches
Jan. 25							26	rain	0.084 inches
Feb. 1				7.8			26	rain	0.030 inches
Feb. 8							30	rain	0.069 inches
Feb. 16				7.6			30	rain	0.131 inches
Feb. 22				7.8			25	rain	0.422 inches

TABLE 5a OBSERVATIONS

1960	Sept. 23 Cells per ml.	%	Sept. 27 Cells per ml.	%	Oct. 4 Cells per ml.	%	Oct. 14 Cells per ml.	%	Nov. 1 Cells per ml.	%
Scenedesmus	$1.25\text{x}10^6$	73	$2.13\text{x}10^6$	88	$7 \text{ x } 10^6$	77	$2.6\text{x}10^6$	70	$.78\text{x}10^6$	55
Chlorella	$0.25\text{x}10^6$	15	$4.7 \text{ x}10^4$	2	$.35\text{x}10^6$	4	$.05\text{x}10^6$	1	$.165\text{x}10^6$	12
Chlamydomonas	$0.1\text{x}10^6$	6	$1.05\text{x}10^5$	4	$.125\text{x}1^6$	1	$.35\text{x}10^6$	10	$.165\text{x}10^6$	12
Euglena			$.9\text{x}10^4$	1						
Chodatella					$.1\text{x}10^6$	1				
Amoeba					$.025\text{x}10^6$					
Pleurococcus			$1.9\text{x}10^3$	-						
Cyanophyta			1.06x105	4	$.727\text{x}10^6$	8	$.4\text{x}10^6$	11	$.05\text{x}10^6$	3
Cosmarium					$.3\text{x}10^6$	3	$.25\text{x}10^6$	7		
Dictyopteris	-		$3.8\text{x}10^3$	-						
Ankistrodesmus	$0.1\text{x}10^6$	6	$2.4\text{x}10^4$	1	$.33\text{x}10^6$	4	$.05\text{x}10^6$	1		
Chroococcus									$.25\text{x}10^6$	18
Others			$1.9\text{x}10^3$	-	$.175\text{x}10^6$	2				
TOTAL	$1.7\text{x}10^6$	100	$2.43\text{x}10^6$	100	$9.1\text{x}10^6$	100	$3.7\text{x}10^4$	100	$1.41\text{x}10^6$	100

TABLE 5b OBSERVATIONS

	1960				1961							
	Nov. 11 Cells per ml	%	Dec. 13 Cells per ml	%	Mar. 22 Cells per ml	%	Apr. 27 Cells per ml	%	Jul. 24 Cells per ml	%	Aug. 24 Cells per ml	%
Scenedesmus	3.7×10^{6}	89	$.1\times10^{6}$	21	$.45\times10^{6}$	15	1.1×10^{6}	96	2.0×10^{6}	46	4.85×10^{6}	100
Chlorella	$.1\times10^{6}$	2			2.3×10^{6}	74	$.05\times10^{6}$	4	$.01\times10^{6}$	-		
Chlamydomonas			$.05\times10^{6}$	10.5					$.3\times10^{6}$	7		
Euglena												
Chodatella					$.05\times10^{6}$	2			$.0125\times10^{6}$	-		
Amoeba												
Pleurococcus												
Cyanophyta												
Cosmarium			$.05\times10^{6}$	10.5								
Dictyopteris												
Ankistrodesmus												
Chroccoccus	$.15\times10^{6}$	4										
Other	$.2\times10^{6}$	5	$.28\times10^{6}$	58	$.30\times10^{6}$	9			2.04×10^{6}	47		
TOTAL ALGAE	4.15×10^{6}	100	$.48\times10^{6}$	100	3.1×10^{6}	100	1.15×10^{6}	100	4.36×10^{6}	100	4.85×10^{6}	100

TABLE 5c OBSERVATIONS

1961	Oct. 12		Nov. 2		Nov. 9		Nov. 23		Nov. 30		Dec. 14	
	Cells per ml	%	Cells per ml	%	Cells per ml.	%	Cells per ml	%	Cells per ml	%	Cells per ml	%
Scenedesmus	2.5x10^{6}	98	4.95x10^{6}	65	2.5x10^{6}	83	1.9x10^{6}	64	1.3x10^{6}	82	2.2x1	56
Chlorella	-		0.5x10^{6}	6	.225x10^{6}	8	.05x10^{6}	2	0.1x10^{6}	6	.075x10^{6}	2
Chlamydomonas	.05x10^{6}	2	0.5x10^{6}	6	.05x10^{6}	2	.45x10^{6}	21	-		-	
Euglena												
Dictyosphaerium			0.9x10^{6}	12								
Chroococcus											1.575x10^{6}	39
Cyanophyta			0.75x10^{6}	10								
Xanthophyceae					.225x10^{6}	7	225x10^{6}	11				
Protozoa									0.5x10^{6}			
Rotifer											.05x10^{6}	
S-Bacteria			.8x10^{6}	-	.35x10^{6}	-						
Other Algae			0.1x10^{6}	1			.05x10^{6}	2	.2x10^{6}	12	0.1x10^{6}	3
TOTAL ALGAE	2.55x10^{6}	100	7.7x10^{6}	100	3.0x10^{6}	100	2.18x10^{6}	100	1.60x10^{6}	100	3.95x10^{6}	100

TABLE 6 OBSERVATIONS

Date 1960	Bod Temp/ Days	Bod Settled Sewage ppm	Bod Effluent ppm	Bod Centrif. Effluent ppm	Reduction ppm	%	Total Solids mg/l	Settled Solids mg/l	Alkalinity Ca CO_3 mg/l
Jul.13	25/5	360	130	37	333	90			
Aug.10	20/5	251	58	27	224	89			
Aug.17	25/5	225	111						
Aug.13	25/5	373							
Sep.28	20/5		65	6					
Oct.12	25/5		89	8					
Oct.26	25/5		91						
Nov.23	25/5		53	3			419	142	46
Nov.30	25/5		43	3			394	222	38
Nov. 2							1900		400
Nov. 9							1075	424	198
Dec.14			(40)	(2)					60

Discussion of Observations at Fairfield (July 1957 to February, 1962)

Although the mal-operation of the pond resulted in periods of septic conditions, sufficient useful results were obtained to enable comparison of several aspects of algal-bacterial symbiosis process as a method for treating settled sewage under Australian conditions with the results obtained in the Californian studies.

(1) Depth and Detention Period

During the period of pond operation the depths varied between 14 and 16 inches (average 15 inches) and the detention periods ranged from 2¼ to 10 days (average 5 days). The range of detention periods used in the Californian studies ranged from 0.7 to 10 days while the depths ranged from 2" to 24".

(2) Dissolved Oxygen (D.O.) in Contents of Pond.

The dissolved oxygen content ranged from zero when conditions were septic to 34.5 ppm when the pond was operating at high efficiency. The D.O. was not studied in as great detail as in California where a 24 hour run using Pilot Plant 11 gave results ranging from 0 ppm D.O. at night to concentrations above 30 ppm during the day (17). During some observations however, the waters in the pond at Fairfield were supersaturated with D.O. at levels several times greater than the normal saturation D.O. values.

All D.O. samples at Fairfield were taken during the daylight hours. The occurrence of the range of observed dissolved oxygen values were as follows.

Dissolved oxygen range ppm	% of Total observations in range
0 - 1	10
1 - 5	5
5 - 12	15
> 12	70

(3) pH Values

Observed pH values varied between 7.2 and 10.0 (average 8.4). Day time values in the Californian experiments ranged from 7.2 to 10.8.

In times of high algal activity the algal uptake of carbon dioxide and release of oxygen may give a resulting pH as high as 11.0. During night time however, the pH may fall to a value as low as 6.8 when little algal activity is taking place. The optimum pH for organic oxidation by bacteria is between 7.5 and 8.0(17.) It is for this reason that the highest B.O.D. reduction rate does not occur during the mid-afternoon period when algal activity and resulting pH values are high.

The occurrence of the range of observed pH values was as follows.

pH range	% of total observations in range
≤ 7.6	40
7.7 - 8.6	30
8.7 - 9.6	25
≥ - 9.7	5

(4) Algal Concentrations

(a) Packed Volume

The packed or centrifuged volumes of the pond's waters include sludge as well as algae but do give an indication of algal concentration. In California analysis of results obtained used Pilot Plant I enabled a relationship to be found between detention period and chlorophyll content at various depths (25). Based on this an estimate was made as to the proportions of algae and sludge in the packed volume. For a four day detention period and a depth of 18 inches, the sludge content was estimated at approximately 15% by volume.

For the Fairfield samples the packed volumes varied between 0.5 ml per litre and 11.3 ml per litre (average 2.9 ml per litre). For the Californian samples the corresponding results ranged from -

0.55 to 4.0 millilitres per litre.

The Fairfield average is considerably higher than that for the Californian tests, but could well be explained by the higher influent B.O.D. resulting in a higher sludge content.

Assuming that the sludge content of 15% remained constant for the samples taken at Fairfield, the packed volume gives an easy method of estimating the algal content.

(b) Algal Counts

Another method of evaluating the algal concentration is by counting under a microscope. Although this method appears to be more direct it takes no account of the volume of individual algae nor their protein content.

The Fairfield samples gave counts ranging from 1.15×10^6

to 9.1×10^6 cells per millilitre. These values fall within the results at California which ranged from -

0.1×10^6 to 6.6×10^6 cells/millilitre

(5) Identification of Algae

Table 5 indicates the genera of algae and other organisms observed by microscopic inspection of the waters of the pond. In the samples taken at Fairfield, Scenedesmus was the most prevalent, for most of the time. At California although Scenedesmus predominated some of the time, it was more often found that Chlorella predominated. Only on one occasion at Fairfield did Chlorella dominate (22nd March, 1961). Both the algae Chlamydomonas and Euglena occurred at various times in the Fairfield pond. Other algae such as Cyanophytae, Pleurococcus, Dictopteris and Ankistrodesmus were observed but only in small numbers.

The Californian experiments have shown that the predominating genera of algae changed with pond operating conditions (17). Pilot Plant 1 experiments indicated the Chlorella increased with increase in detention period but decreased with increase in depth. Scenedesmus appeared to decrease both with a decrease in detention period but also with a decrease in depth. In the Pilot Plant 11 experiments there was a slow seasonal change in the algal genera.

It seems likely that the nutrients in the effluent sewage and climatic conditions influence the genera.

(6) B.O.D. Reduction

Table 6 indicates the B.O.D. reduction at Fairfield ranging from 89% to 90% (two values only obtained). The Californian results gave reduction from 42.3 to 96.0%.

It can be seen that the results in Column 5, Table 6 are considerably higher than those under Column 4, Table 6 which were analysed without algae. This is due to the natural respiration of the algal cells as described by reference (29). This results in the uptake of oxygen from the dilution water which should not be considered as part of the B.O.D. of the pond's waters.

A comparison between the results obtained at Fairfield and the results obtained at Richmond, California is given by Table 7.

TABLE 7

COMPARISON OF FAIRFIELD WITH CALIFORNIA RESULTS

PARAMETER	RICHMOND	FAIRFIELD
Depth (in.)	2 - 24	14 - 16
Detention Period (days)	0.7 - 7	2 - 10
Temperature ^{o}C	11 - 29.2	12 - 30
Influent Sewage		
Total Volatile Solids (ppm)	139 - 302	240 - 330
Suspended Solids (ppm)	32 - 127	110 - 240
BOD_5 (ppm)	24 - 355	170 - 240
NH_3-N (ppm)	6.5 - 48.6	28 - 60
Organic N (ppm)	3.4 - 28.8	5 - 21
pH	7.0 - 7.9	7 - 8
Alkalinity (ppm)	162 - 302	150 - 275
Contents of Pond		
Algal Cells		
(a) No. per ml. x 10^6	0.1 - 6.6	1½ - 2½
(b) Packed cell Volume (ml/l)	0.55 - 4.0	2 - 4
(c) Dry weight algae plus sludge (ppm)	31 - 1008	400 - 1100
(d) Production Rate lb. (dry)/acre/day.	6 - 200	30 - 400
BOD_5		
(a) Total (ppm)	50 - 618	40 - 130
(b) Supernatant liquid (ppm)	5 - 11	3 - 3.7
pH	7.2 - 10.8	7 - 8.8
Alkalinity (ppm)	48.3 - 320	40 - 200
% BOD_5 reduction	42.3 - 96	80 - 92

Fairfield Pilot Plant (May 1965 to date).

No work on the Fairfield Pilot Plant was carried out during the period February 1962 to May 1965.

Work recommenced in May 1965 when one of the authors, Mr. M. McGarry arrived from Canada to study algal-bacterial symbiosis using the pilot plant at Fairfield for the degree of Doctor of Philosophy under the supervision of the other author Dr. J.B. Clampett and Professor C.H. Munro in the School of Civil Engineering at the University of New South Wales.

During the period since May, 1965 several changes have been made to the control and operation of the pond. The electrical and pumping systems have been altered to conform with those shown in Figure 12. The modified system has operated satisfactorily during the months of October, November and December, 1965.

The influent system as shown in Figure 13 has been constructed to maintain predetermined water levels. The influent sewage is being taken from an upflow settling basin at a depth of three feet. The intake check valve has been surrounded by a loose fitting net to avoid the intake of larger settling particles. This affords a measure of protection to the solenoid valve which closes off the influent line when the pump is shut off by the depth gauge. An influent pump is necessary as choking of the influent line would result if only gravity flow was relied upon.

The effluent pump as shown in Figure 14 is operated by an adjustable synchronous timing switch. In this way a predetermined detention period can be maintained. The pump is primed by a priming tank and has been fitted by a syphon break to avoid the

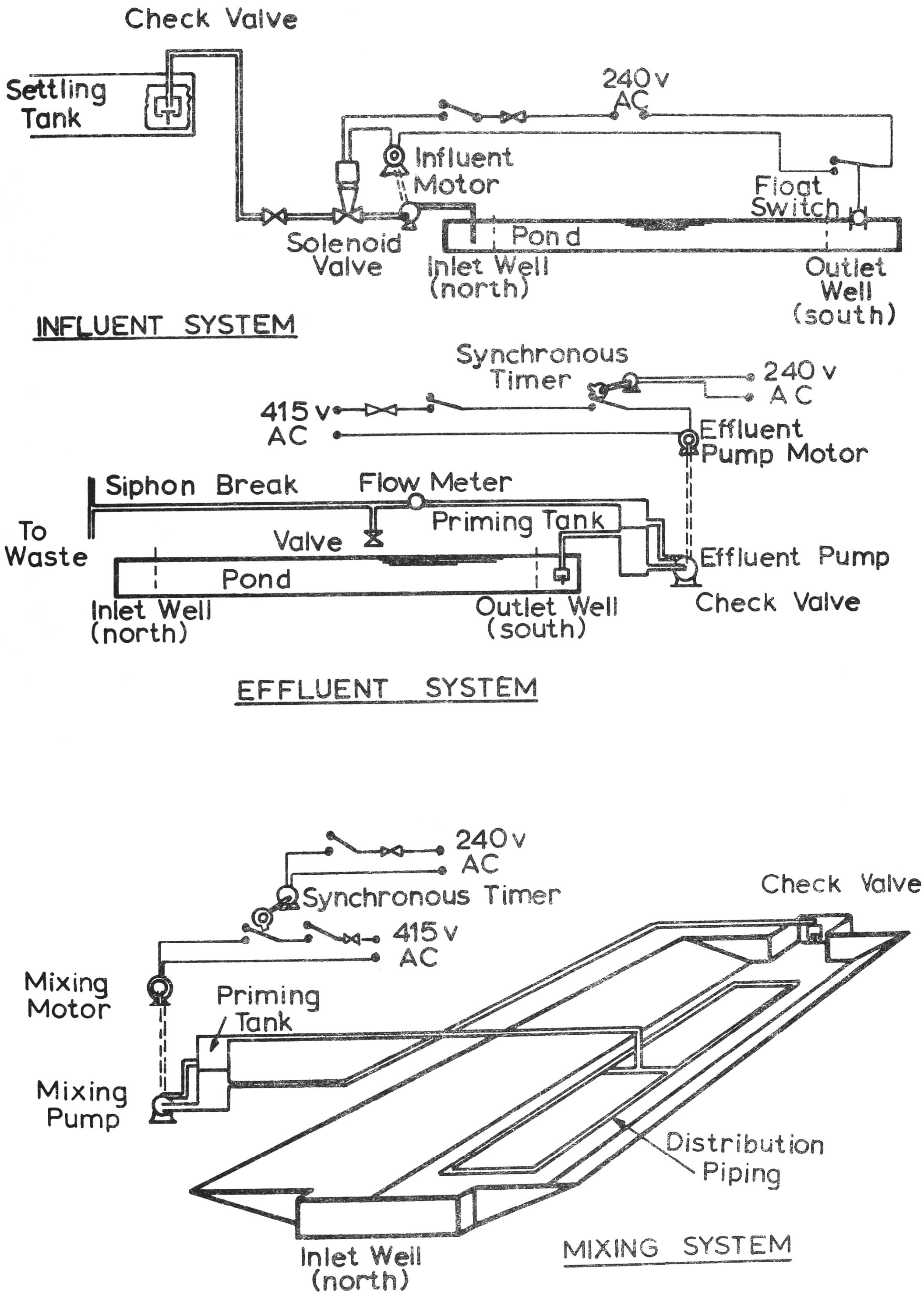


FIG. 12. INFLUENT, EFFLUENT AND MIXING – ELECTRICAL AND FLOW DIAGRAMS. (1965 - 1966)

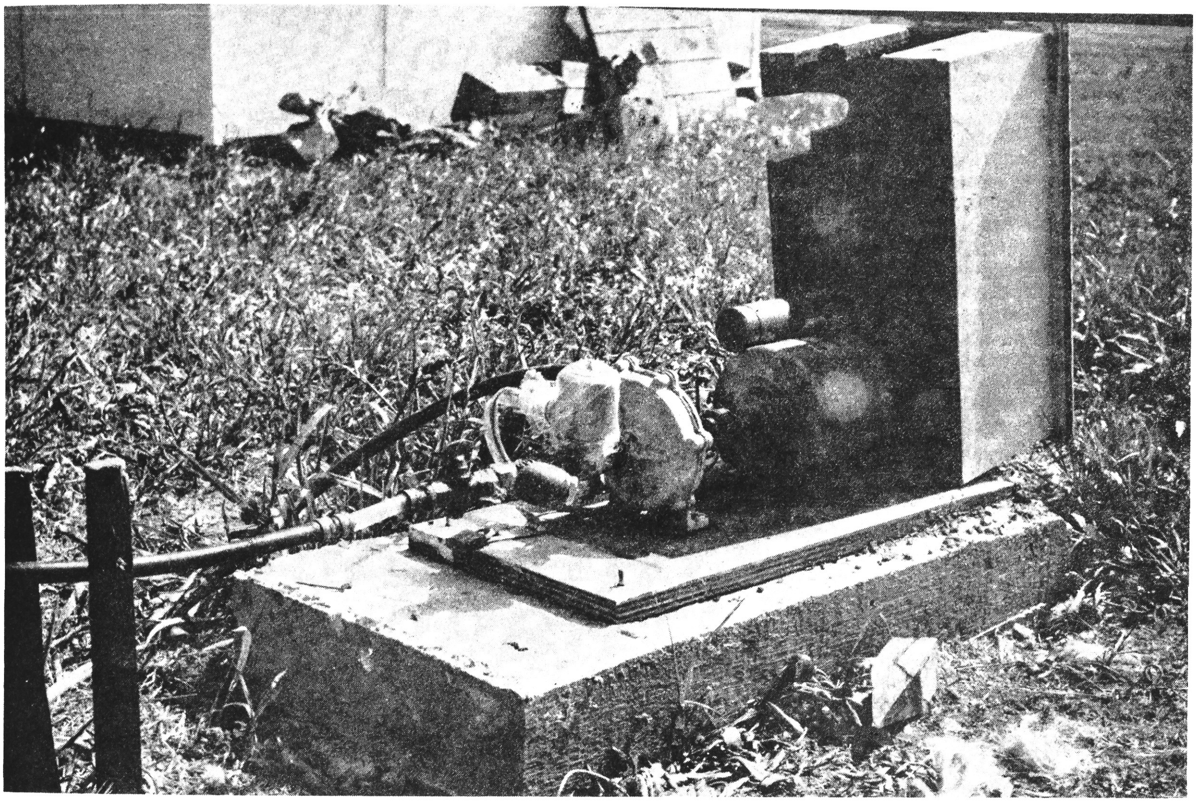


Figure 13. View of Influent Pump with cover removed showing solenoid valve.

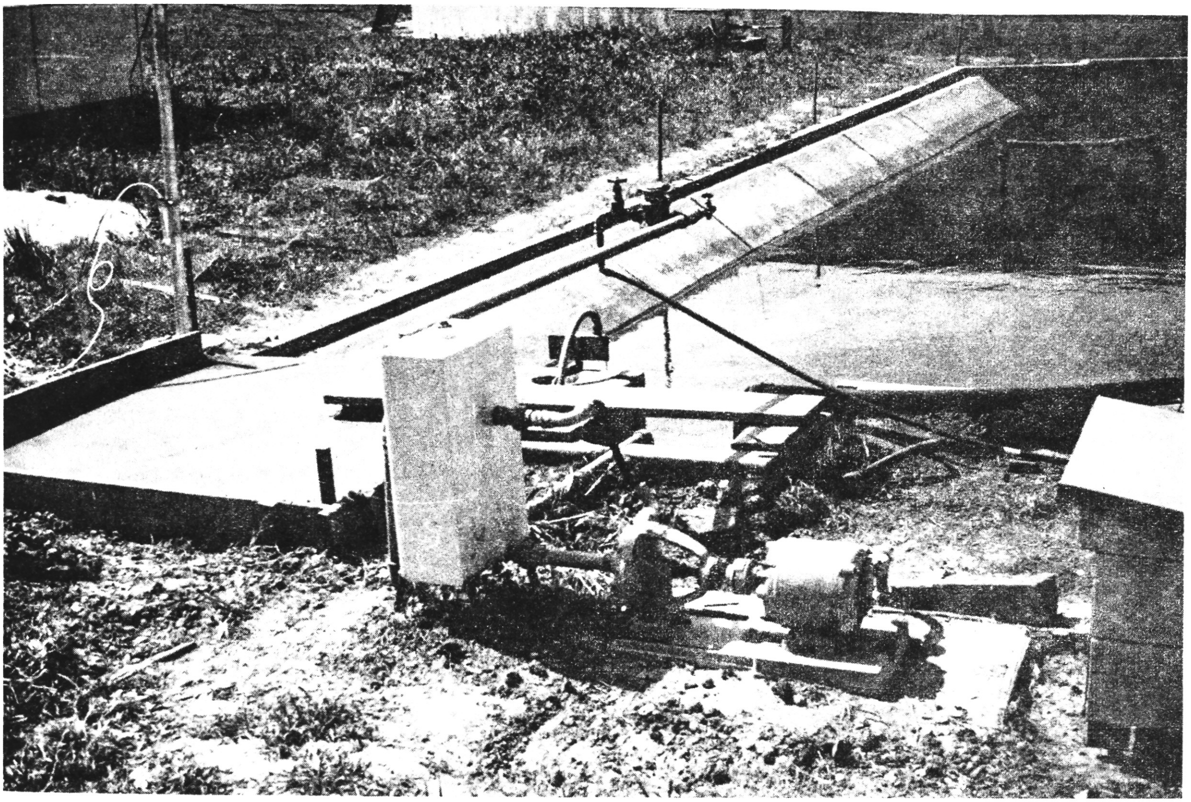


Figure 14. View of Effluent Pump and Effluent Well at Southern End of Pond.

syphoning of the pond waters when the pump is not in operation. An integrating flow meter has been installed on the effluent line.

The mixing system has been altered and is now controlled by a 24 hour synchronous timer. The influent check valve has been relocated in a deeper portion of the pond and is protected by a loose nylon screening thus avoiding any larger particles from entering the distribution pipes of the mixing system. A general view of the pond and mixing system is shown in Figure 15.

In the near future a multichannel recorder and upflow solids contact unit are to be installed. It is hoped that within the next two years the techniques which are required to separate and concentrate the algal content of the high rate pond waters will be further improved. The continuation of this research is well under way.

Laboratory Facilities at Fairfield (from October, 1965).

Due to the biological nature of the analyses to be carried out it is essential that the samples be tested immediately following their extraction from the pond. Transportation of samples from Fairfield to Kensington or Ultimo for analysis would result in erroneous and unreliable results, due to the long transportation time required. A programme involving analyses every two hours would be impossible under these conditions.

In view of this, one of the authors, (Mr. McGarry) set up a laboratory beside the pond. The floor of the laboratory is of four inch reinforced concrete with walls and roof of "Fibro" on a wooden frame.

The building is internally lined with "Masonite". Two windows, a lockable door and an exhaust fan have been installed.

A recent photograph of the laboratory is shown as Figure 16. The Metropolitan Water Sewerage and Drainage Board have placed eighteen single-phase and three three-phase points inside the building. An internal fuse box has been installed inside the building and an external fuse, synchronous timer and switch box as shown in Figure 17 has been mounted on the outside.

A sink, hot and cold water supply, and drainage system have been installed. Benches, shelves and cupboards have been located in the building. The necessary glassware, chemicals, 20°C incubator-refrigerator, 37°C incubator, 3°C refrigerator, spectrophotometer, dissolved oxygen meter, muffle furnace, drying oven, centrifuge, steam bath, microscope, hot plates, pH meter, vacuum-compression pump, general balance, accurate analytical balance and autoclave have been installed in the building.

Figure 18 shows a plan of the layout of the laboratory.

Future Programme

As depth, detention period, influent sewage strength, algal type and solar radiation have been found to strongly influence the yield of algal material and the percentage reduction of B.O.D. through the pond an extensive programme is now being undertaken to establish these influences. Both depth and detention periods are being varied over a wide range and their effect being observed.

Following the adjustment of the pond to any chosen depth and detention time the physical and chemical conditions in the pond will be measured every second day until the state of equilibrium is established in the pond with respect to algal yield. The analyses which are being carried out on the influent sewage include:

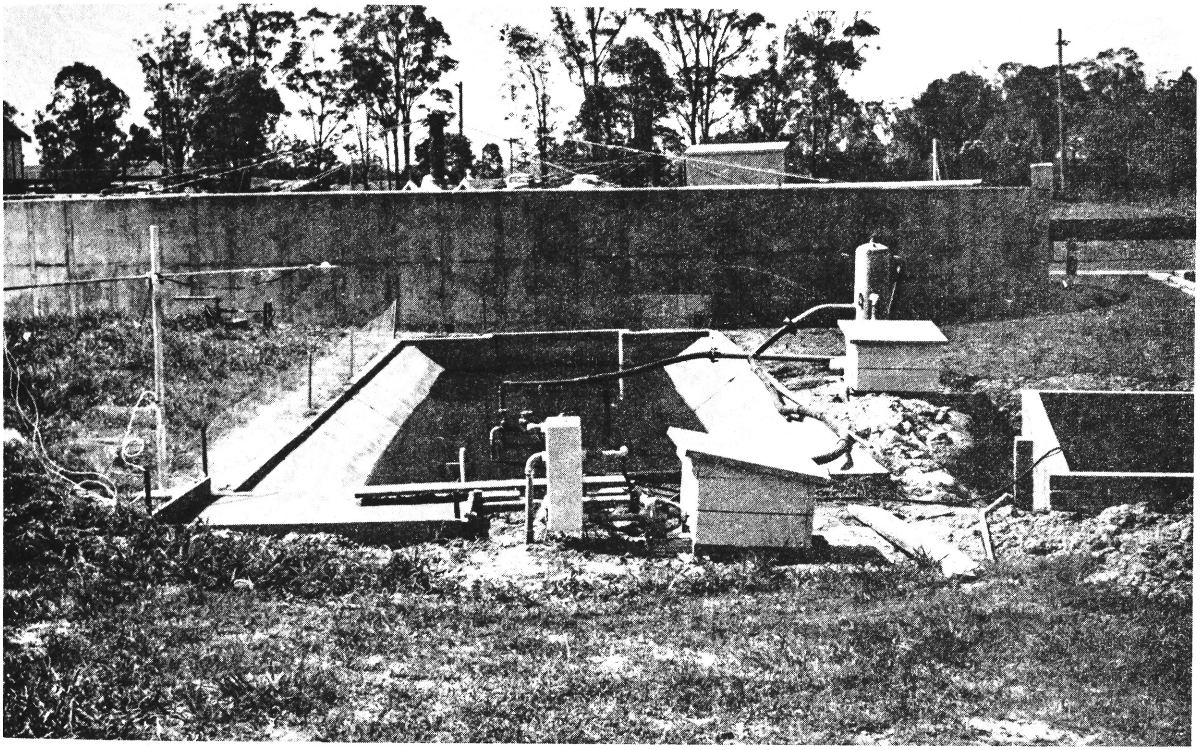


Figure 15. View of Pond Looking North (Nov. 1965)

The mixing pump can be seen at right and the effluent pump in the foreground. The radiometer in the left foreground and influent pump in the left background have been installed since the project was recommenced in May, 1965.

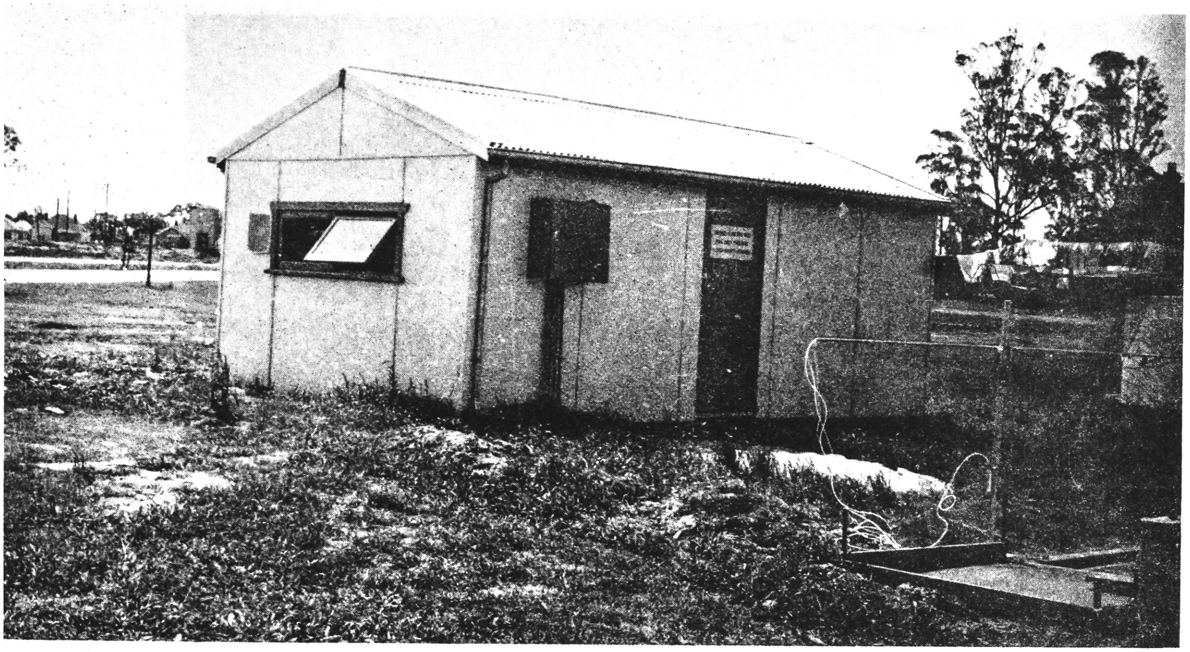


Figure 16. View of Research Laboratory at the Fairfield Sewage Treatment Plant of the Metropolitan Water, Sewerage and Drainage Board.

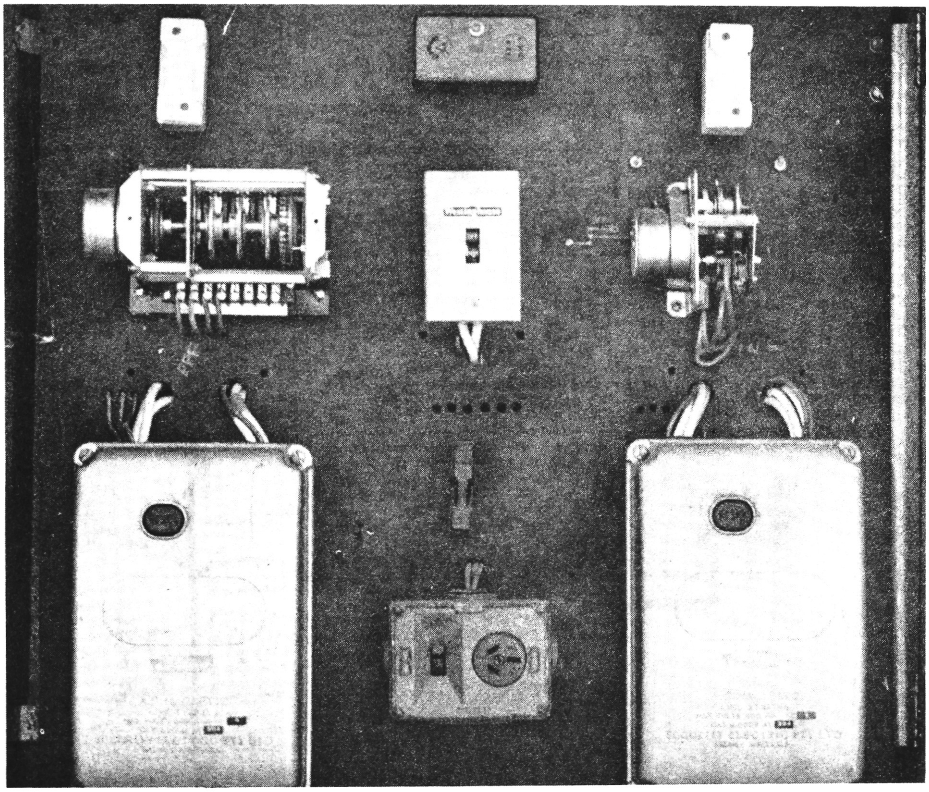


Figure 17. View of Control Panel showing synchronous timers (with covers removed), Fuses and Switching Gear.

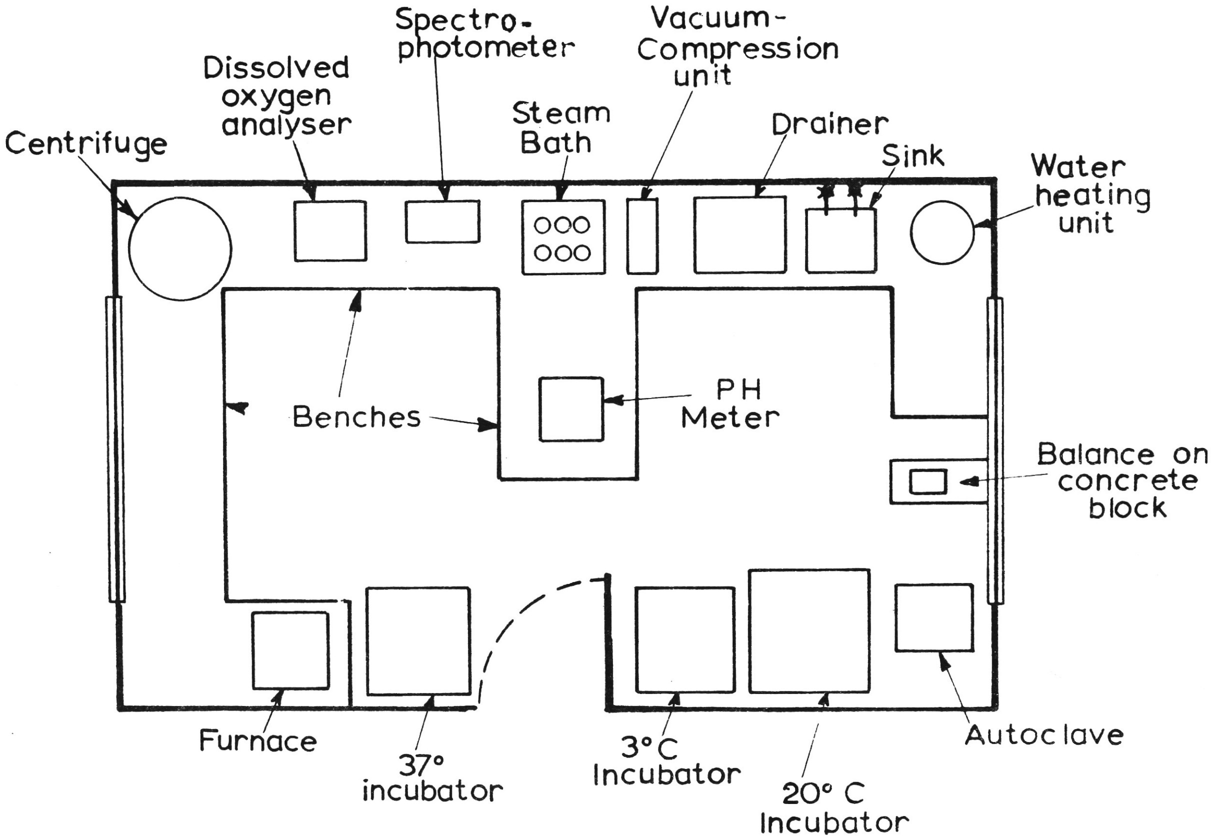


FIG. 18 LAYOUT OF RESEARCH LABORATORY
AT FAIRFIELD
(Dimensions 20' x 13')

1. Hydrogen ion concentration
2. Alkalinities
3. Total Volatile solids
4. Total Non Volatile solids
5. Biochemical Oxygen Demand
6. Orthophosphates
7. Ammonia Nitrogen
8, Total Nitrogen, organic
9. Sludge accumulation

The analyses which are being carried out on the pond culture include:

1. Hydrogen ion Concentration
2. Alkalinities
3. Dissolved oxygen
4. Total volatile solids
5. Total non-volatile solids
6. Biochemical oxygen demand
7. Cell yield
8. Cell count
9. Orthophosphates
10. Ammonia nitrogen
11. Total nitrogen, organic
12. Chlorophylls, A, B and C
13. Packed volumes
14. Total light energy at all depths
15. Light energy incedent on the pond's surface
16. Ambient and pond temperatures
17. Net radiation

After the pond has reached its equilibrium stage of growth, a twenty four hour test is performed. The hourly influent analyses include:

1. Hydrogen ion concentrations
2. Alkalinities
3. Biochemical oxygen demand

The pond culture will be studied through the following hourly analyses:

1. Hydrogen ion concentrations
2. Alkalinities
3. Dissolved oxygen at all depths
4. Biochemical oxygen demand
5. Temperatures at all depths including ambient
6. Light energy received at all depths
7. Visible light intensities at all depths
8. Net radiation

In this way the diurnal fluctuations in the pond culture will be observed. These analyses will establish BOD reductions, oxygenation factors, stabalization factors and cell yield including protien production of the pond at the various imposed depths and detention periods.

The second and third phases of the study will begin within six months following the completion of the first phase. The use of an upflow solids contact basis will be studied using various chemical coagulants and polyelectrolytes. Simultaneously a study will be carried out on the drying characteristics of the algal concentrate using drying bed and plate techniques.

In this way the feasibility of sewage treatment and food production through high rate ponds will be established for use in Australia.

PRACTICAL APPLICATION OF ALGAL-BACTERIAL SYMBIOSIS:

It has been established both in California U.S.A. and Fairfield N.S.W. that the process of algal-bacterial symbiosis will reduce the level of pollution of settled sewage. The reduction in BOD_5 of the contents of the pond during the process relative to the influent's sewage has been shown to be considerable in both cases.

As the algal content of the water in the pond on several occasions at Fairfield was removed by centrifuging, tests were carried out to determine the B.O.D. of the supernatant liquid after centrifuging. A comparison of this $B.O.D._5$ value with the $B.O.D._5$ level in the influent sewage gave an indication of the level of B.O.D. reduction which could be obtained. The B.O.D. reduction at Fairfield was observed to be 90% and 89%.

These above reductions in the $B.O.D._5$ value of the influent settled sewage compare more than favourably with the other sewage treatment methods, particularly facultative oxidation ponds, trickling filters and activated sludge processes. Table 8 gives approximate values of the $B.O.D._5$ loadings of treatment per unit of available area.

It is estimated that B.O.D. loadings of above 300 lbs. B.O.D. per acre per day are possible in High Rate Oxidation Ponds. This has been borne out by the Fairfield experiments. This represents a loading of six times that of the conventional facultative pond and a considerably cheaper form of sewage treatment than the conventional type of plant, dependent of course on the land costs.

TABLE 8

B.O.D.$_5$ Loadings for Several Sewage Treatment Processes.

Process	Max. B.O.D.$_5$ Loading lb. per acre per day.
High Rate Pond, Fairfield, N.S.W.	360
Richmond, U.S.A.	634
Facultative Pond	125
Anaerobic Pond	5,000
Intermittent Sand Filter	150

Practical Application of High Rate Oxidation Ponds as a means of Sewage Treatment in Australia.

It is clear that for the widespread practical application of high rate oxidation ponds using algal-bacterial symbiosis the effective removal of the algae from the liquid effluent before disposal is necessary for several reasons:

(1) to obtain the greatest reduction in B.O.D. of the effluent

(2) to avoid discharging the algae into the receiving stream

(3) to obtain any benefit from the protein content of the algae.

As the most important prerequisites of the high rate algal oxidation pond is the separation of algae from the pond waters if the process is to be used as a method of treating sewage, no definite conclusion can be drawn on the Fairfield experiment with regard to its use as a complete treatment process. Only following the completion of tests on an algal removal process can conclusions be drawn on its future use.

Although the B.O.D. analyses were infrequent, these results serve as an indication of the efficiency of the algal bacterial symbiosis in sewage treatment. As previously noted the B.O.D. of the pond waters with algal cells in suspension give no reliable indication of the pond waters B.O.D. due to their respiration in unnatural conditions. These reduction efficiencies are quite within the range of observations found in the Californian investigations.

It is noted that the climate in New South Wales is more suited to the algal-bacterial process than the climate in California where a severe winter often occurs. As a result the cost per capita in sewage treatment could be expected to be lower in New South Wales than that in California.

Algal Removal and Concentration

The high rate pond waters contain a heavy load of organics in the form of algae which may induce an oxygen demand from the receiving body of water if it is not extracted from the pond waters before discharge.

In a recent publication (30) Drs. C.G. Golueke and W.J. Oswald of the University of California, Berkely, U.S.A. describe experiments which they have carried out in the separation and concentration of algae. It was realised early in the programme that the operation should be divided into three steps - (1) Initial Removal (2) Dewatering and (3) Final Drying.

(1) Initial Removal. It has been found that the initial removal presents the greatest difficulties in the algal processing due to their sizes (5-15 micron) and their low specific gravity (30). The natural settling rate of algae is too slow to allow this method to be used in the initial removal. The methods which have been tried are centrifuging, precipitation, ion exchange, chemical precipitation by flocculation, autoflocculation, flotation, microstaining, passage through a charged field, sonic vibration, and filtration.

Centrifuging involves the use of continuous centrifuges causing the initial costs of removal to be high and in many cases prohibitive. Three types of centrifuges were tried in laboratory, pilot plant and field scale studies. The laboratory studies were carried out to observe the effects which differing centrifugal forces have on the degree of removal. Addition of chemicals also tried. It was observed that although the chemicals added did have beneficial effects, these were small in view of their costs. A continuous centrifuge with through-put rates of 0 - 2 U.S. g/m was used in the pilot plant studies which proved sufficiently successful to allow the use of a Dorr- Oliver-Nerco continuous (0 to 400 U.S. g/m) centrifuge in the field scale studies. It was observed that at a through-put rate of 300 g/m, the power required to remove one ton of algae was less than 3500 Kilowatt-hours.

In the precipitation of the algae studies were carried out to observe the relationship of the hydrogen ion concentration to the tendency of the algae to clump together and thereby settle more rapidly. This principle of obtaining a higher rate of settling through the addition of chemicals is known as flocculation. The effect of calcium, magnesium and sodium ion was also considered. It was observed that the optimum pH (measure of hydrogen ion concentration) of the suspension of clean washed algae was 3 for the most efficient removal of algae. This pH was effected through the addition of sulphuric acid.

The clumping together of the algae was effected through the algal suspensions passage through cationic exchange resins. This was brought about by a change in the surface charge on the algal cells effected by the resins. Ives (31) has shown that the density of the surface charges on Chlorella is a function of the pH of the suspension. He observed that the highest densities were effected by pH values of 3.5 and 10.5 and the lowest at 7.0. The hydrogen ion acts not only to satisfy the charges at the lower pH values but also acts as a bonding agent. Examinations through the microscope indicated that the algae were so tightly clumped together as to deform the side of contact of the individual algal cells.

Chemical precipitation was studied through the use of cationic flocculants namely the synthetic poly-electrolytes Sondellite and the Puriflocs 601 and 602. Although the Puriflocs were only studied on a small scale, it was confirmed that with the low dosage of 10 mg. per litre of Purifloc, 95% removal of the algae was effected. The Sondellite was studied on a pilot plant scale, through a dosage of 4 mg. per litre of reagent, 90% of the algae were removed after a flash mix of 35 seconds, a slow mix of 4 minutes or a 4 hour detention period in a settling tank. Lime was used to raise the pH level in another test and it was found that the most effective pH in precipitation was 10.6. The use of iron hydroxides resulted in excellent precipitation of algae but the algae were coloured orange and some of the cells disintegrated. A combination of $Ca(OH)_2$ and $FeSO_4$ could reduce the cost of reagents considerably. The use of aluminium sulphate (Alum) was studied in a laboratory, pilot plant and field scales. In contrast to the organic polyelectrolytes, alum showed a dependency upon the pH remaining around 6.5 in the removal of algae. It was observed that at a dosage of 70 mg. per litre of alum above 11 mg. of algae per mg. of alum was precipitated. The possibility of aluminium removal from the slurry was studied. Very low B.O.D. values and coliform counts of the clarified effluent were observed. The clarified effluent has been described as "sparkling clear" (30).

Autoflocculation is the natural rapid precipitation of active photosynthesising shallow culture on warm days of abundant sunshine. Algal recovery would be possible if the supernatant liquid was drawn off and the remaining liquid allowed to evaporate. The land costs which would be involved in such a scheme would be prohibitive.

Several flotation reagents were tried, however appreciable concentration was successful with only two at a critical pH of 4.0.

Microstaining was tried on a pilot plant scale at flow rates of 50 to 100 g/m. However the screen aperture size was too large and a smaller aperture size would have resulted in clogging.

Copper, carbon and aluminium electrodes were used either in pairs of the same material or in pairs using two different materials. Excellent floc formation occurred when aluminium and/or copper were used due to the release of these metals to form aluminium and/or copper hydroxides.

Algal cells were subjected to sonic waves of 1500 cycles and above in an effort to force them together. However quite the reverse resulted and experimentation with sonic vibration ceased.

Experiments were carried out on a laboratory scale with filters of 0.1 ft. in diameter. The algae were able to pass through all the filters with the exception of bacteriological filters at an exceedingly low through-put rate.

Complete removal of algae was established with the use of filter aids such as diatomaceous earth, however the residue was 7/8 filter aid. Due to the high cost of the filter aid, filtration has been shown to be economically unsuitable.

(2) Dewatering. The resulting effluent from the initial removal was in the form of a thin slurry. Attempts to dewater the slurry were made by centrifuging, gravity filtration and vacuum filtration.

Four types of centrifuges were used to dewater the slurry.

These were the Byrd solid bowl centrifuge, the Tolhurst Solid Bowl, the DeLaval and the Nerco Bowl. Attempts with the Byrd proved unsuccessful due to the low viscosity of the slurry. The Tolhurst Solid Bowl was not continuous. The Nerco Bowl centrifuge was continuous and removal of over 75% was obtained. The DeLaval centrifuge is not continuous but has a through-put rate over eight times the Tolhurst and is being used in research work on the nutritive properties of algae.

Gravity filtration was attempted through the use of nylon, wool felt, canvas, paper and paper backed with sponge rubber. All retained the algal floc, but nylon proved the more durable. All industrial filter papers proved satisfactory.

It was observed that the type of backing to the filter media did not effect the rate of dewatering. Measured in inches of loss of depth per hour, the original loss was 1.5 at a slurry depth of 3 to 4 inches to .05 to .1 inch/hour after 6 hours of dewatering. At the end of 24 hours the solids concentration ranged from 8 to 14 percent. It was established that water loss was, to the greater extent, due to percolation and drainage.

A Delpark mechanical filter was used to dewater the algae on a continuous belt. It was observed that the concentration of dewatered algae was inversely proportional to the belt speed above one inch per minute.

Efforts to dewater through vacuum filtration failed due to the inability of the algae to form a layer thick enough to permit its removal. Filter aids did not help the situation sufficiently.

(3) Drying. Two methods were tried in performing the final drying. These were by heat and by sand bed.

Two types of heat drying equipment were used, both being of the drum-kiln type, one being heated by infra-red lamps from the outside and the other by steam heat from the inside.

The former caused algal deterioration due to the infra-red rays and also the accumulation of large balls consisting of a dry exterior but a wet, cooked and ill smelling interior.

Successful drying was accomplished with steam drying.

The Dewatering and Drying processes have been combined into one through the use of sand beds. The slurry from the initial removal is spread in depths of up to five inches over sand. The water both percolates or drains and evaporates being irradiated by the sun. The sandbed is estimated to be 15% of the pond area. After 24 to 48 hours the dewatered slurry had a solids content of 7 to 10 percent and the consistency of soft cream cheese. The moisture content of the algal product was 15 to 20% after 5 to 7 days after which it formed chips of 1/8 inch in thickness. The relatively small amount of sand adhering to the chips was removed through screening by hand and by a Sweco vibrating screen. In this way 80 - 90% of the sand was removed. Although this method has disadvantages such as the destruction of photolabile vitamins, it does represent the least expensive method which may be applicable to use where land costs are low and low quality algae are satisfactory.

Algal Production Costs.

Cost estimates have been made on a variety of methods and plant capacities. The following discussion does not include the growth of the algae, uses 1964 American dollars and assumes a plant capacity of 10 million U.S. gpd. of influent sewage. The amortization and interest were assumed to aggregate 10% of the total installed cost. The total installed cost covers the purchase price of the machinery, power supply, piping installation of accessory equipment and a warehouse type of shelter. Electrical power was based on an 8 hour daily operation at 10 mills/Kwh. The average cost of personnel was assumed to be $6,000 per man per year.

The cost of processing by centrifuging for the removal and dewatering and steam drum drying is estimated at $116 per million gallons of sewage. If the algal suspension were treated by inorganic flocculation and then by sand bed drying the quality of the algae would be considerably reduced but the cost per million gallons of sewage would be $67. If autoflocculation were successfully used to remove the algae followed by sand bed drying the corresponding cost is estimated at $42.

The cost of algae per pound is influenced considerably by the initial algal concentration. If the initial removal was by organic polyelectrolyte, dewatering by centrifuging and drying by steam drum, the cost per pound of algae would be $0.05 if the concentration of algae in the pond effluent was 1.5 tons/ million U.S. gallons. This would result in an algal product which has a good appearance, is readily digestible and the quality of clarified water is low in BOD and coliform count.

CONCLUSIONS

Although the records of the work carried out at Fairfield during the period July, 1957 to February, 1962 are incomplete, it is clearly apparent that the process of algal-bacterial symbiosis can be successfully employed to purify settled sewage under climatic conditions in New South Wales. The results of this work clearly showed:

(1) That the results obtained in experiments in Richmond, California were valid under conditions at Fairfield, N.S.W.

(2) That the degree of purification achieved (even without algal recovery) compared more than favourably with other equivalent local treatment methods.

Considerable research and development is necessary before the process can be used for sewage treatment in large scale plants. The most important aspects are:

(1) Recovery of algae from the waters of the pond before discharge into a receiving stream

(2) The evaluation of pond parameters so that a more accurate forecast of the algal population can be made according to depth, influent sewage strength and detention period.

To obtain the necessary data for (2) it would be necessary to control these three variables extremely carefully. As the Californian experiments were carried out over 2,000 days and occupied more than 10 scientists for 10 years without obtaining the all necessary information under the required conditions, it is clear that a major research project on a scale not possible in Australia would be required.

For the above reason it has been decided to continue the project involving the pond at Fairfield by investigating the removal and concentration of algae from the pond effluent. The removal and concentration techniques to be investigated include upflow coagulations and sand-bed drying. The project involves the continued operation of the pond under as near to optimum conditions for maximum algal production as possible. Several refinements to the pond operation have been made, so that such conditions can be maintained to assist the study of algal removal and concentration.

It was evident to the authors in the early assessment of the work carried out from 1957 to 1962 that the main reason for the lack of necessary data was the failure to provide adequate laboratory facilities adjacent to the pilot plant pond. This restricted the number of samples that could be taken and gave erroneous results as no refrigerated transport was available for the period during transportation to the laboratory. With completion of the installation of the laboratory facilities alongside the pond, the authors have every confidence that, given adequate assistance and support, the project will develop and provide a major contribution in the field of high rate oxidation pond operation and subsequent removal and recovery of the algae produced.

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