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A guide to the use of pond systems in South Africa for the purification of raw and partially treated sewage

NATIONAL INSTITUTE FOR WATER RESEARCH

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FOREWORD

The National Institute for Water Research of the South African Council for Scientific and Industrial Research has for some years conducted research on the use of pond systems for the purification of effluents. The results of these investigations have found their way to the public in a number of publications and consequently pond systems have found progressive application in this country.

The economic advantages, simplicity of construction and ease of operation and maintenance of stabilization and maturation ponds for sewage purification and effluent beneficiation for reuse carry with it an inherent danger in that the systems are so simple they are not recognized as an engineering venture, such as a conventional sewage purification plant. Pond systems require proper planning, proper application, design, maintenance and periodical review with reference to pond loading.

A further factor responsible for laxity in pond management is the fact that these systems provide better barriers against pollution in the event of mismanagement than conventional sewage works.

As time passed, however, it appeared that through lack of knowledge, or misappreciation of essentials, there has been a deviation from suggested criteria for the design and construction of these ponds. These deviations have, in some instances, caused the ponds to fall into disrepute. The present document is, therefore, an attempt to combine knowledge and experience gained thus far with the results of further research. This document could thus serve as a reference for planning new systems and for improving existing installations.

In using maturation pond systems for humus tank effluent treatment, biological activity is harnessed:

(a) to minimize the hitherto uncontrolled eutrophication of rivers, natural lakes and impoundment reservoirs receiving purified effluents;

(b) to provide an effluent amenable to more advanced purification.

It is a relatively new field of research and the present document will, therefore, have to be revised constantly as new knowledge is gained.

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CONTENTS

A GUIDE TO THE USE OF POND SYSTEMS IN SOUTH AFRICA FOR THE PURIFICATION OF RAW AND PARTIALLY TREATED SEWAGE

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1. INTRODUCTION

Water Act No. 54 of 1956 provides for the promulgation of standards to which effluents must comply before return to a watercourse. In terms of the Act, it is in fact obligatory to return a purified effluent to a river for use by other persons entitled to the use of water from that river. The Act empowers the Minister to authorise other means of disposal, but the Act obviously does not envisage that such other means of disposal should be generally adopted.

Some of the effluents from the sewage purification systems covered by this report show quite marked seasonal variations. No assurance can be given that the effluents would meet promulgated standards from season to season. The effluent from stabilization ponds will, in summer, contain high concentrations of algae, whereas in winter high ammonia concentrations will be found.

The shortcomings of these systems must, however, be seen against the background of their application. Instances can be quoted when the introduction of stabilization ponds has brought about a great improvement in the environmental situation which, for practical or economic reasons, would not otherwise have been possible.

However, in view of the deficiencies mentioned above, the use of stabilization ponds must, in terms of the Water Act, be subject to a permit from the Minister of Water Affairs.

2. GENERAL CONSIDERATIONS FOR POND SYSTEMS

2.1 Definitions

Within the context of this guide, the following definitions of terms apply:

Pond Systems

Any pond system intended to fulfil a biological waste treatment requirement, utilizing bacteria and algae.

Stabilization Ponds

Ponds used for biological stabilization of raw or partially treated waste waters.

Maturation Ponds

Ponds used for treatment of well-nitrified humus tank or sand-filtered effluent.

Anaerobic Pond

Stabilization pond with anaerobic conditions obtaining throughout.

Aerobic Pond

Ponds which are almost completely aerobic, with no or only a small anaerobic bottom layer.

Aerobic-anaerobic ponds

Ponds in which aerobic conditions prevail near the surface and anaerobic conditions in the bottom sediments and lower water levels. Those ponds are also referred to as facultative stabilization ponds or simply as facultative ponds.

Anaerobic-aerobic stabilization pond system

A system in which anaerobic ponds are followed by facultative ponds from which oxygenated water is recirculated to the raw waste water entering the anaerobic ponds. The system is considered as a primary unit in a series of ponds. (Refer section 6.4).

2.2 How a pond operates

A diagrammatic representation of different pond systems are given in Figure 1. The relative pond areas required are indicated. An improvement in effluent quality is represented by the relative movement across the spectrum to the right. The range varies from the completely anaerobic pond for treating raw sewage to completely aerobic maturation ponds treating sand-filtered humus tank effluent. Mechanically-assisted ponds in which all or much of the oxygen requirements are supplied by mechanical aeration, are not indicated in this diagram.

A pond system may be designed to treat either night-soil, raw sewage, settled sewage or sewage works effluent. The design depends on the treatment objectives, but this type of waste treatment process is most suitable for locations where -

(i) land is inexpensive,
(ii) climatic conditions suitable,
(iii) organic loadings fluctuate considerably, and
(iv) funds are limited.

Pond systems have often been used to satisfy interim waste treatment requirements for treatment of sewage in small quantities.

The process depends on the effective use of bacteria for degradation of putrescible organic material and usually green algae for oxygenation purposes. A mutual relationship exists between algae and bacteria: The bacteria are the primary workers, which have the ability to effectively break down and utilize many complex organic waste materials, whereas the algae with the assistance of fungi, utilize the simpler degradation products. At the same time the algae produce oxygen for use by the aerobic bacteria.

As long as the algae can provide an excess of oxygen above that required by the bacteria, a relatively aerobic environment will at least be maintained in the upper layers of the pond. Under these conditions, aerobic organisms can degrade the organic material. Part of the substrate will be used to make new cells, and the remainder of the substrate will provide the energy that is necessary to further the degradation reactions.

If sufficient oxygen is not provided, as in the bottom layer of a stabilization pond, anaerobic bacteria or facultative bacteria (i.e. bacteria which can function under either aerobic or anaerobic conditions) will obtain the required oxygen from chemical compounds and produce various types of organic acids, alcohols, etc. The anaerobic process, as compared with the aerobic process, is relatively more complex and will produce more odoriferous conditions. Except in completely anaerobic ponds, the anaerobic bottom layer is sealed off from the atmosphere by an aerobic surface layer.

Most ponds develop to varying degrees into combination anaerobic-aerobic treatment units. In this respect, ponds are very similar to rivers and lakes. Aerobic conditions are frequently maintained near the surface and sometimes throughout most of the pond. However, because organic debris frequently settles out, an anaerobic environment will persist near the bottom.

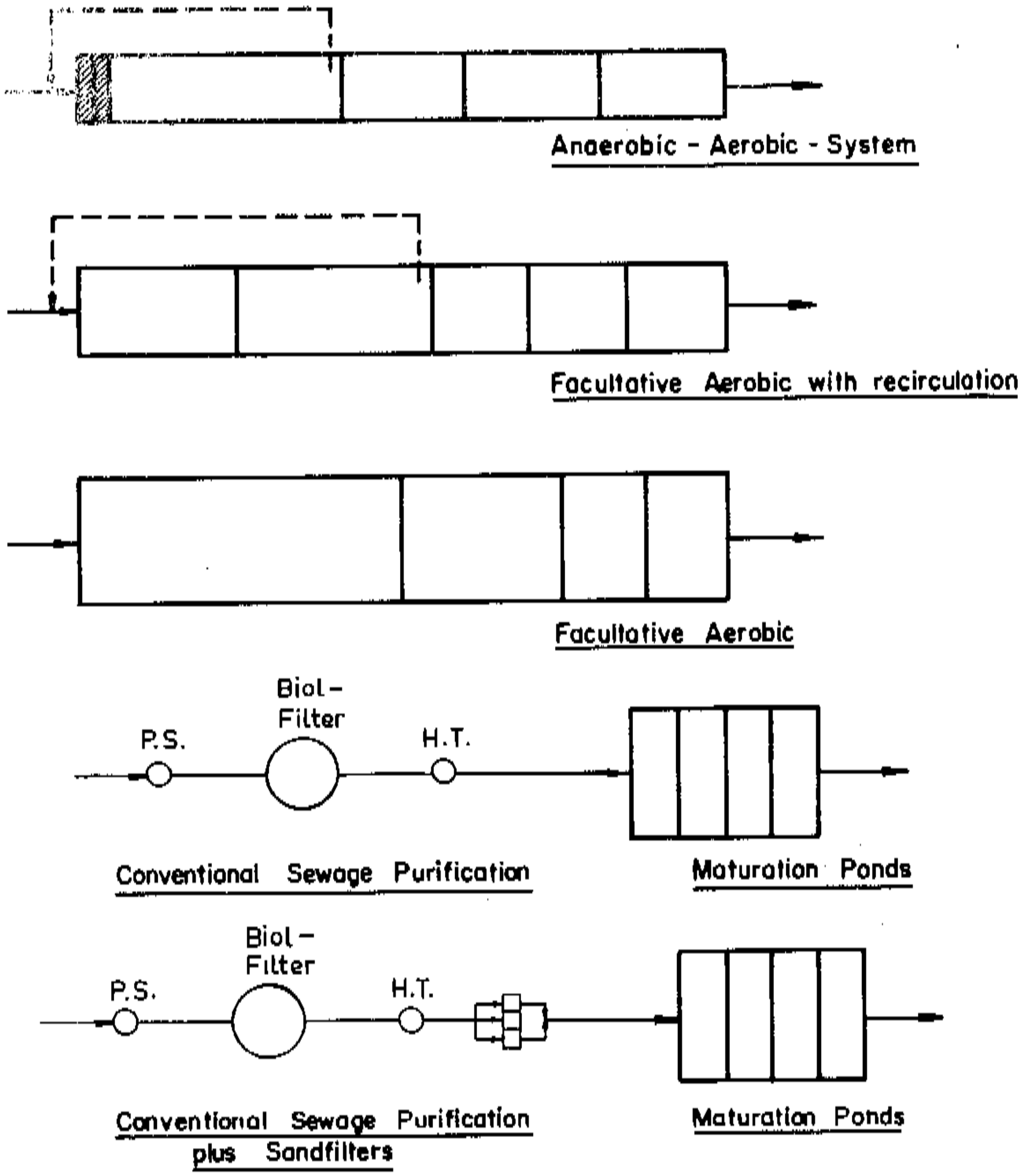


FIGURE 1

Pond systems - Range of applications

(Pond areas approximately proportional)

The effluent put into maturation ponds should already be well stabilized in a conventional sewage purification works. As the effluent from a series of stabilization ponds is also well stabilized, the final ponds in such a series also perform the function of maturation ponds. Purification effected in maturation ponds is primarily with respect to bacteriological quality although some chemical improvement is also achieved. (When treating a humus tank effluent which contains very little suspended solids, a maturation pond may cause the apparent deterioration of this effluent because of algal development).

2.3 Temperature

Temperature is of paramount importance in the design of pond systems. It affects photosynthetic oxygen production as well as other biological reactions. While optimum oxygen production is obtained at about 20°C, limiting lower and upper values, respectively, appear to be about 4°C and 35°C. Above 22°C increased anaerobic fermentation results in the formation of mats of sludge on the surface, buoyed up by occluded gases. When water temperatures approach 35°C in warmer climates, particularly when ponds are shallow, the beneficial algal population will be severly curtailed.

2.4 Topography and siting

Any pond system for waste treatment should be well protected against wash-aways and the entry of natural run-off. Provided this can be ensured, there is no reason why the pond design should not be adapted to the surrounding topography as it may cost less to include existing depressions or valleys in the scheme rather than to fill them in.

The least amount of earth moving for the construction of ponds is usually required on land of gentle slope. However, it should be noted that this same land is not necessarily the most suitable for the construction of a sewage purification plant of conventional design which may at a later stage replace the stabilization pond system as a sewage treatment facility.

Aerobic-anaerobic (facultative) stabilization ponds, properly maintained to keep mosquito-breeding in check, need not be sited more than 500' away from a residential area. Anaerobic ponds can usually be operated to cause no smell nuisance. However, it is not always possible to eliminate fly-breeding in such ponds, and for this reason anaerobic ponds should be situated at least half a mile away from any residential area. All ponds should be fenced in.

2.5 Land requirements

It is advisable that all land between the sewage purification plant - whether it be stabilization ponds or a conventional sewage purification plant - and the nearest watercourse should be acquired and owned by the owners of the purification plant.

A nett pond area of facultative ponds of approximately 5 acres must be provided for a flow of domestic sewage of 100,000 gallons per day. Additional allowance for embankments, dividing walls and access roads must also be made. The above requirements of 5-acre pond area will differ with other wastes and other types of ponds. The extent of land required for irrigation purposes, if practised, amounts to between 20 and 40 acres per 100,000 gallons per day of irrigation water.

2.6 Versatility of application

(i) Treatment of night-soil (1)

Stabilization ponds can, in many instances, be put to excellent use to relieve existing conventional sewage purification works by treating night-soil and/or conservancy tank effluent rather than discharging these liquids to the sewer and thence to the sewage purification works. If the ponds are sited adjacent to the existing sewage plant, humus tank effluent can be used profitably for topping up purposes.

(ii) Decentralized treatment facilities (2)

Where stabilization ponds are to be used on an interim scheme (or even otherwise), it may be economically profitable to operate a number of small units on temporary sites close to the source of the effluent until such time as it becomes justifiable to install a main collecting sewer.

(iii) Treatment of septic tank effluent (3)

Facultative stabilization ponds can be profitably employed for the disposal of pre-treated effluent such as derived from septic tanks and aqua-privies or the effluent from a primary anaerobic pond with recirculation as described in Section 6, page 24.

(iv) Increased sewage treatment capacity (4, 5)

By introducing a quantity of settled sewage with the nitrified effluent from a conventional works to the first of a series of maturation ponds, a marked reduction in the nitrate concentration can be achieved without otherwise materially affecting the quality of the final effluent.

(v) Advanced effluent treatment (6, 7, 8) (maturation ponds)

The use of ponds for further treatment of humus tank effluent is being practised very widely in South Africa. Primarily, these ponds are used to obtain an effluent of high bacteriological quality, but it has been shown that advanced biochemical purification is also obtained in these ponds as for instance illustrated by the further reduction of synthetic detergents. This improvement in chemical quality, as indicated by the normal sanitary parameters, is frequently masked by prolific algal activity.

The biological processes which improve a sewage effluent chemically and bacteriologically are unlikely to alter the virus content significantly, but ponds, nevertheless, have a gratifying ability to bring about virological purification (9). The removal of viruses probably depends upon their adsorption onto static surfaces and their exposure to the rays of the sun. According to the aforementioned reference, it is concluded that from the virological point of view, a pond system should be as shallow as possible and so extensive that the retention period exceeds the normal survival time of an infectious virus. This stresses the importance of preventing short-circuiting and points towards the necessity of having a number of ponds in series.

The development of an efficient technique to remove algae from pond effluents (see Section 11) and the feasibility of denitrifying humus tank effluent in a pond system, have opened new horizons for employing maturation ponds for effluent reclamation.

2.7 Contamination of groundwater, seepage losses and sealing of ponds (10)

Groundwater pollution from seepage must always be regarded as a possibility. From tests reported in the literature, it would appear that where the pond bottom is in the zone of aeration above the water-table, the migration of bacterial pollution would be slight (of the order of 20 feet). Where seepage from the pond is directly into an aquifer, bacteria may migrate for several hundred feet, the migration being generally in the direction of flow of the groundwater.

In certain geological formations, where the groundwater travels in fissures or channels, instead of permeating slowly through the soil or rock pores, the possibilities of dangerous pollution of underground waters are much greater.

It is obvious from the data presented in Table 1 that seepage losses can be high and vary over a wide range according to the geology of the pond base and the composition of soil used in the construction of the walls. Consequently the prevention of pollution of underground water supplies and the curtailment of losses where the reclamation of water for reuse is of primary importance, necessitate special attention be given to site selections and the sealing of pond base and walls.

If a pond is to be constructed in a soil of high porosity, i.e. having a very low clay content, or on an unsound geological formation such as found in dolomitic areas, the danger of groundwater pollution could be real. It would then be advisable to take steps to seal the pond bottom.

Such sealing could be effected by the importation and compaction of a layer of suitable soil on the floor of the pond, or otherwise with plastic sheeting. In the last instance, special care must be exerted since the sheeting is easily ruptured and where it is exposed at the water's edge it should be covered in to protect it against hail stones and the perishing effect of ultra-violet light. Plastic sheeting is also subject to bulging if the soil underneath contains organic material which, because of anaerobic fermentations, would produce gas.

It will be noticed from Table 2, page 12, that sealing of a pond approximately doubles its capital cost.

TABLE 1

REPORTED SEEPAGE RATES FROM POND SYSTEMS

Literature Source	Initial Rates					Eventual Rates				Geology of Pond Base	Place
	Initial Seepage Rate		Hydraulic load gals/acre/d	Seepage Rate as % of Hydraulic Load	Settling-in Period	Eventual Seepage Rate		Hydraulic Load gals/acre/d	Seepage Rate as % of Hydraulic Load		
	ins/day	gals/acre/d				ins/day	gals/acre/d				
California[11, 12]	8.8	199,000	316,000	63	9 months	0.35	7,940	± 380,000	2.1	Desert Soil (Sandy Soil)	Mojave, California
*Neel and Hopkins[13]	5.5	127,850	141,970	90	1 year	0.61	13,810	47,323	29.2	Sand and Gravel	Kearney, Nebraska
+Voights[14]	-	-	-	-	Average over 5 years (1951-55)	0.34	7,660	9,160	84	Sandy Soil	Filer City, Michigan
CSIR[15]	6	136,000	54,000	Exceeded inflow rate	± 1 year	0.3	6,800	50,000	13.6	Clay loam and Shale	Pretoria
Windhoek Mun. xMaturation Ponds[16]:											Windhoek, S.W.A.
Nos. 5	0.16	3,500	776,000	0.45	Over period 14th-22nd June 1967 after all ponds in full operation	-	-	-	-	Mica and Schist	
6	0.17	3,900	1,190,000	0.32		-	-	-	-	Mica and Schist	
7	0.015	300	712,000	0.046		-	-	-	-	Mica	
8	0.06	1,400	715,000	0.19		-	-	-	-	Mica and Schist	
9	0.23	5,300	455,000	1.15		-	-	-	-	Mica and Schist with side wall seepage to river	

NOTE:

* Evaporation and rainfall effects were apparently not corrected for. Seepage losses were also influenced by a high water table at times.

\+ These lagoons were constructed in sandy soil with the express purpose of seeping away Paper Mill NSSC liquor.

x Ponds constructed for the express purpose of water reclamation.

2.8 Sludge accumulation

The accumulation of sludge and its effect on the continued performance of a pond requires still further study. However, in a facultative pond, equilibrium between BOD deposited and BOD released from the anaerobic sludge layer into the overlying water, as products of fermentation, is attained after about four years. Since there is a very slow build-up of stabilized sludge which is very resistant to further, biological degradation, it must be accepted that a primary facultative pond receiving raw sewage must either be cleaned out or replaced after about nine to twelve years of continued use since, after such period, the overlying water becomes too shallow (less than 2'6") for continued satisfactory performance.

The removal of sludge from any of these ponds should present no problem since it is well stabilized and may be amenable to pumping by suction pump mounted on a raft without emptying the pond or to lifting either manually or by mechanical means after emptying the pond and leaving the sludge to dry.

The sludge accumulation resulting from the treatment of primary and secondary treated domestic wastes is practically negligible.

2.9 Mosquito-breeding

Mosquito-breeding in any of the ponds is best prevented by keeping the verges free from vegetation and to have the ponds open to wind action. See also "Health Aspects".

2.10 Fly-breeding

Fly-breeding would normally not give rise to nuisance except in the case of anaerobic ponds. (See section 6.3).

TABLE 2

RELATIVE COSTS OF SEWAGE TREATMENT FACILITIES

Population	Capital cost in Rand/person			Running costs/Year in Rand/Person	
	Conventional purification works	Facultative Pond Systems		Conventional purification works	Pond System
		Without sealing of bottom *	With sealing of bottom **		
240	70	6	12	-	1.0
1,000	43	6	11	5	0.6
3,000	31	5	10	3	0.3
5,000	29	5	10	-	0.3

* Cost of construction estimated at ± R3,000 per acre.

** A rate of ± 60 cent per sq.yd. has been assumed for sealing of pond bottoms, both primary and secondaries.

2.11 Maintenance

It would seem that the less the maintenance required on a particular purification plant, the more likely it is to be totally neglected. A special appeal should, therefore, be made to operators to ensure that ponds are properly maintained in general, particularly by guarding against overloading, by keeping the verges free from vegetation, by removing vegetation from within the ponds, and generally by keeping the ponds in an aesthetically pleasing condition by removing and burying any unsightly floating debris. Leakage on the embankments from crab or rat holes must also be guarded against. Any neglect in this respect can impair the efficiency of purification.

2.12 Water-borne sanitation for small and isolated communities

Table 2 is based on information obtained from various sources on actual existing installations. Cost data (Table 2) reveal an interesting comparison between the costs involved in the construction and running of conventional sewage purification systems and facultative pond systems for similar sized communities, and emphasizes the fact that pond systems are ideally suited for providing water-borne sanitation for small and isolated communities who cannot afford the construction of conventional treatment facilities.

3. MATURATION PONDS

Maturation ponds as such are not intended to cater for underdesigned conventional sewage purification facilities or to obviate the extension of an overloaded works or to save on costs of operation and supervision. Maturation ponds are biological units in which a well-nitrified humus tank or sand-filter effluent is purified to give a water of high bacteriological quality (6, 7, 9, 17, 18).

3.1 Pond appurtenances

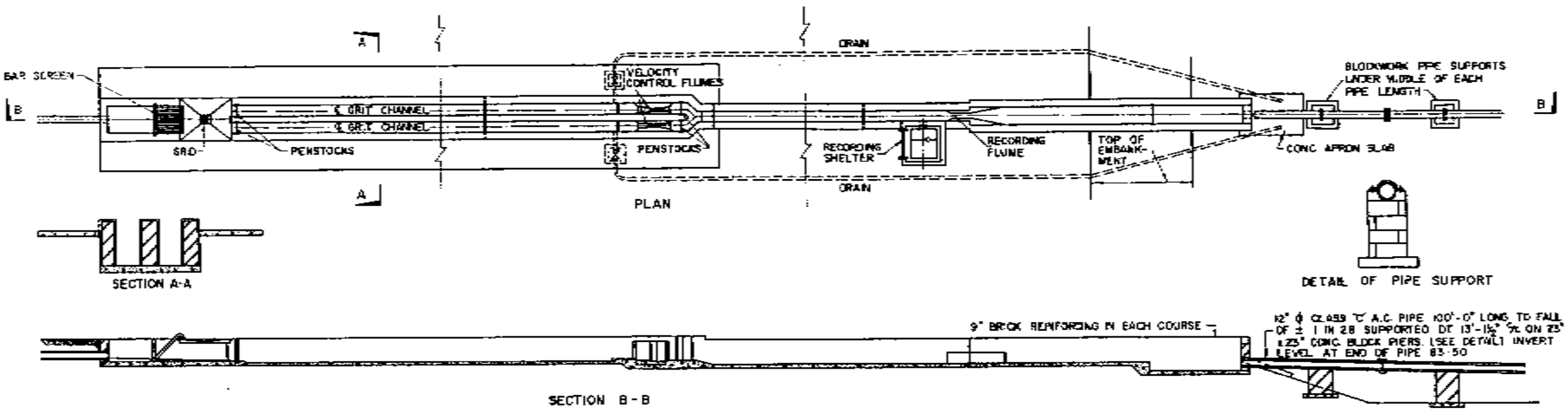
Bodily displacement of the contents, i.e. river flow conditions, cannot readily be obtained in a pond since short-circuiting would inevitably occur. In view of this tendency, maximum average detention must be strived after. This can be achieved by setting the other extreme condition, that of complete mixing, as the ideal and to this end pond appurtenances must be constructed and sited with great care. In this connection the following points are mentioned:

(i) Water discharging from the inlet pipe often has considerable momentum, which may result in short-circuiting. The inlet, which should preferably discharge near the bottom of the pond, should also be directed away from the outlet end of the pond and preferably into likely stagnant pockets, such as may occur in pond corners. This applies to the inlet to each pond.

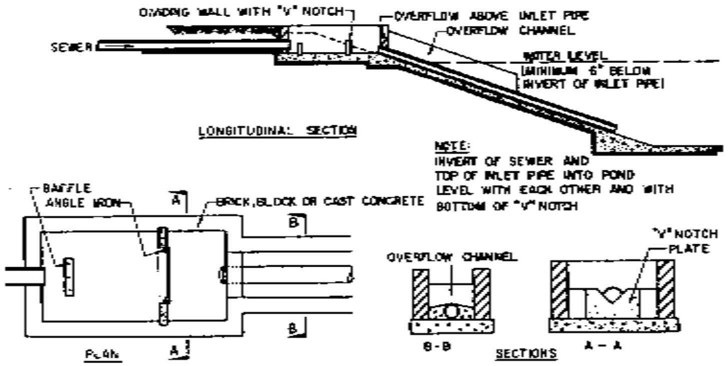
If this is not possible, some means of dispersion of the flow should be adopted.

(ii) Outlets taking water off the surface are not recommended, due to short-circuiting in winter caused by thermal effects of streaming and sheet spreading of the warmer influent along the surface. On the other hand, a deep sub-surface draw-off facilitates short-circuiting in summer since the cooler influent tends to move along the bottom. As a compromise, submerged or baffled outlets are preferable as the effects due to thermal stratification will be reduced and floating scum will be prevented from passing out with the effluent. The baffle should reach to about one foot or eighteen inches below the surface. Examples of inlet and outlet arrangements are shown in Figure 2.

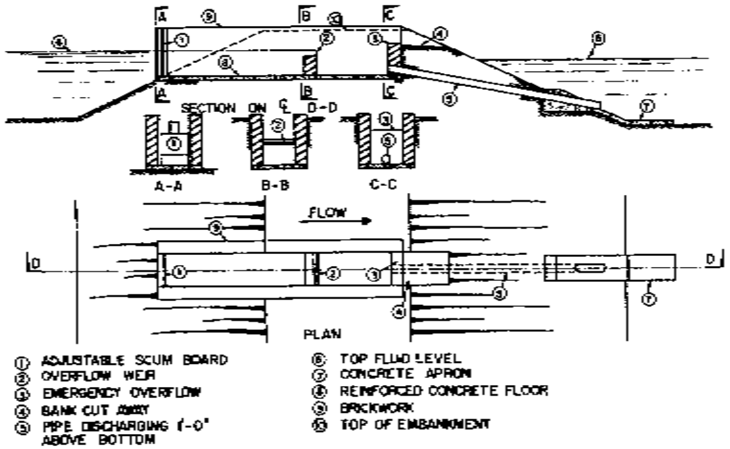
When succeeding ponds are at the same level, submerged oversized connection pipes could be used which would greatly reduce the momentum of the outflowing water. This, however,



Typical bar screen grit channels v. recording flume for large scale installation



Typical measuring box and inlet for small scale installations[9]



Diagrammatic sketch of pond outlet[20]

FIGURE 2

Typical inlet and outlet arrangements

may bring new problems, as despite the considerable retention time provided in pond systems, if oversized connection pipes or weirs are provided, it will be found that peak or surge discharges entering the first pond are not balanced out, and a similar peak outflow from the final pond will follow within a very short space of time.

This is due to the fact that very little build-up of head is needed to convey the peak or surge through the whole pond system. A highly variable rate of outflow would be undesirable where effluent is to be pumped to a point of re-use, or where chlorination or some other form of final treatment is to be practised, as equipment would have to be large enough to cope with peak loads, and would have to be adjustable to cope with constantly varying flows.

Under such circumstances connection pipes or overflow weirs between ponds should be of the minimum permissible size; this will make it possible to use the capacity of the ponds themselves to balance out surges. For ponds to deal with up to 150,000 gallons per day, when flow balancing is needed, 4" diameter pipes, or overflow weirs 6" wide, are suggested. It is not expected that blockage of 4" pipes or 6" weirs will often occur, but emergency overflows should be provided.

An alternative to using the capacity of the ponds as balancing storage, is of course to build an additional dam for storing effluent from the final pond, and to withdraw from the storage dam at a constant rate.

(iii) Where possible or feasible, multiple inlets and outlets should be provided to counteract stagnation in certain corners of the pond.

3.2 Sizing and arrangements of maturation ponds

The retention time in a maturation pond and the configuration of a series of ponds receiving humus tank effluent or sand-filter effluent are determined primarily by the measure of bacterial purification required. Unless the effluent which is to be treated has received only limited stabilization, a maturation pond cannot readily be overloaded to become anaerobic and only practical considerations would therefore dictate the size of such ponds.

The die-off of faecal bacteria in aerobic ponds follows a monomolecular law provided good mixing is assured, i.e. the rate of die-off is more or less inversely proportional to the bacterial concentration (21). This die-off is reflected in the following equation which gives the relationship, expressed as percentage, between the concentration of bacteria in a single pond (N) to the influent concentration (N_o) for varying detention times:

$$100 \left(\frac{N}{N_o} \right) = \frac{100}{(KR + 1)}$$

where R = detention time in pond (days)

K = velocity constant (tentative value assumed to be 2).

The value of K has been established empirically and has been shown to vary considerably in sympathy with the extent to which short-circuiting and seasonal effects, such as hours of sunshine, influence pond performance. However, the value of K has never been observed to be less than 2.2, and until more data are availabla showing to what extent improved prevention of short-circuiting, for instance, would enable the designer to use an increased value for K, a K value of 2 is recommended for design purposes.

The advantageous effect of having a series of small ponds instead of having one big pond of the same overall size is illustrated by doubling the detention time in the above equation. The relationship then becomes

$$100\left(\frac{N}{N_o}\right) = \frac{100}{(K2R_1 + 1)}$$

However, if instead a second pond of equal size is added in series, the relationship between the quality of the effluent from the second pond and the primary pond influent would become -

$$100\left(\frac{N}{N_o}\right) = 100\left(\frac{1}{KR_1 + 1}\right)\left(\frac{1}{KR_1 + 1}\right)$$

$$= \frac{100}{(KR_1 + 1)^2}$$

By inserting any figure for R the superior performance of a series of ponds would become evident.

According to the above equation, four ponds in series each having four and a half days retention and properly operated, should give a 99.99 per cent reduction in faecal bacteria concentration. Five ponds in series, each having three days' retention, would perform even better.

3.3 Target effluent quality requirement:

(i) Bacteriological:

It has been established that the bacteria E. coli I, as determined by the MPN method and present in the effluent from any particular pond, have a logarithmic normal distribution with a logarithmic standard deviation (S) not exceeding 0.45(17). From this information it is therefore possible not only to set a quality requirement for a pond effluent, but also to stipulate an upper confidence limit on a rational basis. Since a biological system is being dealt with, a confidence limit is considered an essential feature of any quality requirement.

For design purposes it should be accepted that an effluent bacteriological count of 1000 E. coli I per 100 ml should be considered the upper limit of the 95 per cent confidence range (exceeded by only 2.5 per cent) of effluent quality. In most instances such effluent should be acceptable for flood irrigation of crops for human consumption that are not likely to be eaten raw, for flood irrigation of fruit and trellised vines, for irrigation of pastures for grazing, for irrigation of golf courses, parks and sport fields, and for discharge into streams.

It can be shown that if the requirement lays down that the effluent concentration, as measured by the MPN method, must not exceed 1000/100 ml with 97.5 per cent confidence, then assuming a logarithmic standard deviation (S) = 0.45, the pond must be designed to give a mean effluent concentration of 132 E. coli I per 100 ml.

Referring to the suggested sizing of ponds in para. 3.2 it is interesting to note that if a humus tank effluent with an assumed E. coli I MPN of 1.32×10^6 per 100 ml is treated in a well designed system of four ponds in series each with four and half days detention, an effluent of the desired quality should be produced since this system should be sufficient to bring about a 99.99 per cent reduction. For treating more highly polluted effluents to the desired bacteriological standard, the bacterial reduction in this system would be insufficient.

(ii) Chemical:

The chemical quality of the effluent is affected by influent quality. A general survey (18) has indicated that four ponds in series, four feet deep, with four and a half days retention each, would produce an effluent with an OA of less than 10 ppm and a COD of less than 100 ppm on a filtered pond effluent sample provided the unfiltered humus tank effluent does not exceed an OA of 20 ppm and a COD of 175 ppm.

3.4 Measuring devices

Knowledge of the flow to the maturation pond system will assist in keeping a check on the pond loading. An integrating flow recorder would not be essential for the influent to the maturation ponds, if the raw sewage is measured. If, however, some of the total flow is diverted for other purposes before reaching the ponds, flow measurements to the ponds would be desirable.

3.5 Embankments

Slopes of embankments should be dictated by normal engineering practice for small dams. Details at fringes should be designed for preventing ingress of vegetation. Capital investment on weed prevention and prevention of wave erosion, by stone pitching or using soil-cement on the pond verges, may well be repaid by saving in maintenance.

4. FACULTATIVE STABILIZATION PONDS

The design for this type of system treating raw or primary treated domestic wastes has been fully covered in CSIR Research Report No. 189(22), from which the essential points are given below:

4.1 General

The first consideration which affects the size and arrangement of a facultative pond system is that a nuisance-free operation is governed by the size of the primary pond.

The second consideration, that of effluent quality, governs the size and arrangement of the subsequent ponds.

4.2 Loading of primary pond

Anaerobic conditions in the surface layers of these ponds result from overloading, which causes the oxygen demand to exceed the reoxygenation capacity.

Overloaded conditions, absence of dissolved oxygen, and odour production are, therefore, mutually associated, and the first condition can be inferred by one or both of the other two manifestations.

For domestic sewage, as well as for stronger and weaker effluents, such as those from aqua privies, septic tanks and settlement tanks (see paragraph 4.3), the following procedure is suggested for estimating the minimum detention time in the primary pond:

Concentration of BOD in the raw sewage influent (23) to the first pond is given by -

$$P_0 = \left(\frac{b}{g} \right) 10^5$$

where P_0 = BOD concentration in the influent to the pond in mg/l

b = BOD contribution per person per day in lb

and g = effluent flow per person per day in gallons.

The minimum detention time in the primary pond

$$R = \left(\frac{P_0}{P} - 1 \right) \times \frac{1}{C}$$

where R = the detention period in days

and C = constant dependent on temperature

and P = maximum concentration of BOD in the pond consistent with aerobic conditions.

As an acceptable value of P, the following empirical formula is given:

$$P = \frac{600}{(0.6d + 8)}$$

where d = the depth of the pond in ft.

Empirical values for C for use in South Africa and South West Africa are suggested in Table 3.

TABLE 3

C VALUES FOR DIFFERENT CLIMATIC REGIONS

Average temp. during coldest month (°C)	Below 5°C	Above 5°C
Geographic region	N.W. Districts, High Veld S.W. and N.E. Free State	Rest of interior and coastal region
C value	0.14	0.17

As a general guide a loading of approximately 120 lbs BOD per acre/day can be adopted for domestic raw sewage in a four-foot deep pond.

4.3 Pre-treatment of sewage

The advantages of pre-treating effluents before discharge to a system cannot be over-emphasized. As a rule of thumb it can be taken that the reduction of BOD in a septic tank or aqua privy of one or more days retention is of the order of 40% which, of course, enables the designer to decrease likewise the size of the primary facultative pond. For small and isolated communities or in instances where less sophisticated modes of sanitation would be acceptable, the above system could be of great economic advantage. The inherent advantages of aqua privies (3) are well worth considering.

The use of anaerobic ponds preceding facultative ponds are described in Section 6.

Another advantage offered by anaerobic pre-treatment of raw sewage before discharge into a facultative pond is that of aesthetics since the floating layer of scum which periodically appears on these ponds is seldom found if pre-treatment is practiced.

4.4 Sizing and arrangement of subsequent ponds

The sizing of the subsequent ponds (i.e. 2nd, 3rd, 4th and 5th pond) is based principally on detention time. A vital feature for efficient reduction of faecal bacteria especially is that the ponds should be arranged in series as demonstrated in paragraph 3.2. It has also been shown that nitrogen reduction is better in a tertiary pond than in a secondary pond, suggesting that nitrogen removals improve with increased overall detention times. It is recommended that a total of at least twenty-five days detention, based on the flow into the primary pond, should be provided in the subsequent ponds.

The first of the secondary ponds should have ten days detention while subsequent ponds in the series (third, fourth and fifth) should have five days' detention each. Further subdivision of the fifth pond should have a further beneficial effect on the bacteriological quality of the final effluent. It should be noted that the E. coli I count in raw sewage could be of the order of 3×10^8 per 100 ml, and that this fact should be taken into account in designing a system of ponds.

4.5 Depth of ponds

The permissible surface loading of the primary pond increases only slightly with increased pond depths. There seems, therefore, to be very little practical advantage in constructing ponds deeper than six feet.

Where by virtue of the topography, a deeper pond, or a pond which is deeper in parts, may be cheaper to construct, it should be taken into account that the ability of the pond to reduce the virus content will be impaired (See 2.6(v)).

Primary ponds shallower than three feet will be unduly affected by sludge deposition and these as well as secondary ponds would possibly also be affected by vegetation growing in such ponds.

4.6 Pond appurtenances

The inlet to the primary pond may require special features to prevent undue accumulation of sludge on one spot. Therefore, features such as multiple inlets to bring about some sludge distribution in the pond may be desirable. Discharge should be below the water level but care should be taken that an accumulation of coarse material does not choke the inlet pipes. Otherwise, with regard to the positioning of inlets and outlets, the same considerations apply as for maturation ponds. (See 3.1).

Pond bottoms may be level or graded to suit topographical features in the best possible way (see paragraph 4.5).

Pond embankments should be built in accordance with paragraph 3.5.

4.7 Measuring devices

A flow measuring or recording device should be installed ahead of the primary pond. Besides a check on pond loading, flow measurement will furnish valuable data for use when the pond system needs extending.

4.8 Screens and detritus channels

To maintain an aesthetically pleasing effect of the ponds, screens and detritus channels correctly sized are usually installed prior to discharge to the primary pond. They may, however, constitute a nuisance, and the cost of attending to same continuously over a period of years would more than cancel the cost of removing accumulated detritus once in five or ten years and to allow for such accumulation* when designing the size of pond. A depression in the pond bottom around and below the inlet to accommodate the accumulated detritus would be an advantage. All screenings and detritus should be safely buried to avoid underground pollution or composted if possible.

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*Bantu sewage usually yields a high grit load because of sand used for cleaning utensils - as high as 1 cu.yd. per million gallons whereas the sewage from White areas may contain one sixth of this amount. Screenings would on an average amount to 8 cu.ft. per million gallons treated.

5. FACULTATIVE STABILIZATION PONDS WITH RECIRCULATION

These ponds constitute an application somewhere in between facultative ponds without recirculation (Section 4) and facultative ponds preceded by an anaerobic pond as described in Section 6.

The performance of a facultative pond is considered as satisfactory as long as the upper layer of the liquid in the pond remains aerobic for the greatest part of the day. Thus, photosynthetic activity in the upper layers must not be overwhelmed by anaerobic conditions proceeding upward from the bottom where active anaerobic fermentation is taking place in the sludge layer. It is therefore of importance that if effluent from a second pond is recirculated and admixed with the raw sewage influent to the primary pond, the loading as calculated on the overall area can be increased considerably without creating anaerobic conditions (24).

5.1 Loading

According to Abbott(21) the BOD load applied to the recirculation pond system (which includes the primary and recirculation pond) can be as high as 250 lbs/acre/day without a nuisance being caused by anaerobic conditions. Considerable overloads can even be withstood by this system for short periods. Until more general information is available, a maximum loading of the primary-cum-recirculation pond of 200 lbs/acre/day is recommended. Recirculation from a secondary pond could be used as a relief measure during periods of overloading of a normal facultative stabilization pond.

5.2 Recirculation rate

At the above loading, the minimum recirculation rate for satisfactory performance seems to be 1 : 1. Provision should, however, be made for higher recirculation rates up to 2 : 1 when required.

5.3 Detention time

A detention period of 18 days is recommended by Abbott for a recirculation pond system (primary and secondary ponds combined) treating domestic sewage of average strength.

The recommended sizing of the pond system would be as follows:

Recirculation pond system	Primary pond detention (based on incoming flow)	- 8 days
	Secondary pond detention	- 10 days
Subsequent ponds	Third pond detention	- 5 days
	Fourth pond detention	- 5 days
	Fifth pond detention	- 5 days

5.4 Pond depth

Pond depths are as described in paragraph 4.5.

5.5 Sludge build-up in the primary pond

It is conceivable that sludge accumulation in the primary pond of the recirculation system will be more rapid than for the normal facultative pond system, so that removal of the residual or non-degraded sludge from the primary pond of the former system may be required more frequently. If the system is not a temporary scheme, being used while a full-scale sewage works is being planned or is under construction, it may be desirable to provide for duplicate primary ponds in parallel so that cleaning operations can be carried out with greater facility. A primary pond with increased depth (say 6 feet), without reduced surface area, would have obvious advantages.

6. ANAEROBIC-AEROBIC STABILIZATION POND SYSTEM (25)

When anaerobic ponds are followed by a facultative pond from which oxygenated water is recirculated to the raw sewage entering the anaerobic ponds, the system is referred to as an anaerobic-aerobic stabilization pond system (An-Ae system). This system is considered as a primary unit in a series of ponds.

In some instances it may be advisable, for aesthetic reasons, to discharge only screened detritus-free sewage into these ponds.

A diagrammatic layout of an An-Ae system is given in Figure 3. The system consists of 3 anaerobic ponds, A, B1 and B2 and one large facultative pond, C, with aerobic surface layers. A pump recirculates water from pond C into the raw sewage entering pond A at a recirculation rate of 25% of the raw sewage flow.

As in the case of the single facultative primary pond (Section 4), the An-Ae system is followed by aerobic ponds (usually four) in series in order to obtain a final effluent of high quality.

Pond A should operate as an anaerobic digester in which active fermentation is established in the sludge layer. As a result of the waste stabilization processes, methane, carbon dioxide and sometimes nitrogen gases are produced. Ponds B1 and B2, which are operated alternately in series with Pond A, remove suspended solids carried over by Pond A effluent, thus obviating unnecessary loading on Pond C. Only two anaerobic ponds are operated at any one time (see Figure 3).

6.1 Pond design and loading of the An-Ae system

It should be noted that these design criteria are tentative and may be altered in the light of further experience. Ponds A, B1 and B2 should be of equal areas and 8 to 12 feet deep. Pond C, which is much larger than the anaerobic ponds, should be 4 to 6 feet deep.

The daily BOD poundage of the raw sewage will determine the pond sizes of the An-Ae system. The volume of Pond A should be calculated on a maximum loading of 0.025 lb BOD/cub.ft/day or a minimum detention of 12 hours, whatever is applicable. Ponds B1 and B2 should be the same size as Pond A.

In designing the size of Pond C, it can be assumed that the anaerobic section of the An-Ae system will remove on an average 60% of the BOD load of the raw sewage.

The size of Pond C is based on an area loading. Pond C should not receive a loading greater than 120 lb BOD/acre/day (see paragraph 4.2).

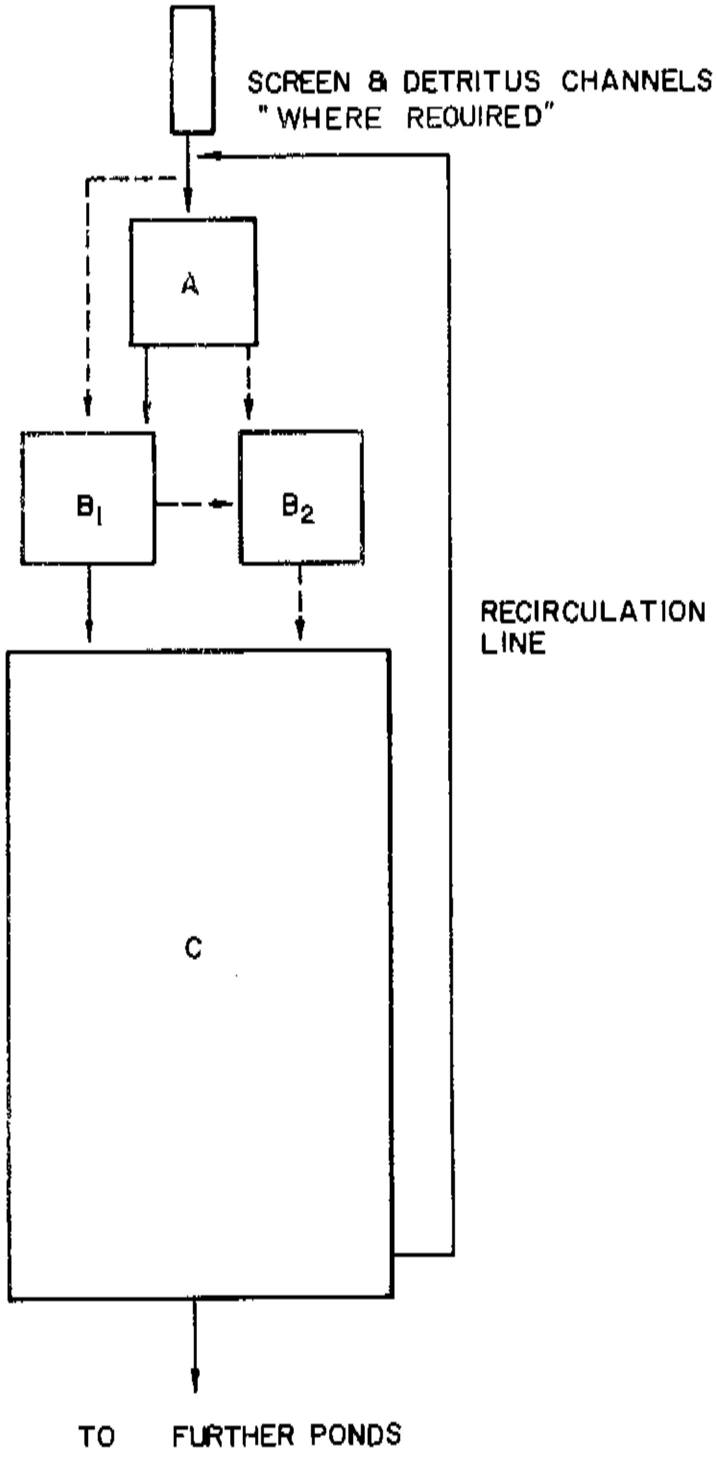

FIGURE 3

Schematic flow diagram of the An - Ae system

The An-Ae system should be followed by not less than three 'polishing' ponds, sized according to paragraph 4.4.

6.2 Sludge accumulation

From an anaerobic pond, sludge may have to be removed once every year. For this reason triplicate anaerobic ponds are recommended, so that the effluent may all be diverted to the one set of ponds while sludge is being removed from the third one. Accordingly, the ponds may be operated according to the following system:

Run 1 : For 6 months, raw sewage to A ——— B1 ——— C.

Run 2 : Succeeding 6 months, raw sewage to A ——— B2 ——— C. Pond B1 to be desludged in interim.

Run 3 : Following 6 months, raw sewage to A ——— B1 ——— C. Runs 1, 2 and 3 to be repeated until it becomes necessary to desludge Pond A (usually 2 to 4 years).

Run 4 : Raw sewage to B1 ——— B2 ——— C, while Pond A is desludged.

6.3 Fly-breeding

Anaerobic ponds are usually covered by a layer of scum in summer. This scum may offer a breeding place for flies. Fly traps containing poison placed at very frequent intervals round the perimeter of these ponds would only partly remedy the situation. It is for this reason that anaerobic ponds should be placed at least half a mile away from the nearest habitation.

6.4 Future application

Although this system is of great technical interest, it is at this stage not recommended for general use in South Africa until more knowledge is available.

7. MECHANICALLY AERATED STABILIZATION PONDS

7.1 Advantages of mechanical aeration

In facultative stabilization ponds, the desirable aerobic conditions in the surface layers are largely brought about by the photosynthetic activity of green algae. If, however, the biochemical dissolved oxygen uptake, such as in an overloaded pond, exceeds the photosynthetic reoxygenation capacity, the critical balance would be upset and the whole pond would turn anaerobic, ousting the algae.

An apparent balance between biochemical dissolved oxygen requirement and photosynthetic reoxygenation capacity of the water in a pond may, however, be upset for reasons other than an increase in pond loading. A drop in temperature or a large and sudden reduction of the algae concentration brought about by an extremely rapid increase in numbers of predator organisms such as daphnia and moina, could well be the cause of such drop in pond performance.

Contributing further to the inefficiency of algae as an oxygen producer is the lack of uniformity of oxygen concentration through all water layers.

To make a pond less reliant on the photosynthetic reoxygenation activity of algae, mechanical aeration of the pond contents could be resorted to. In the United States of America it has, for instance, been shown (26) that at loadings of 400 lb BOD per acre per day, an overall efficiency of about 90 per cent BOD reduction could be achieved even while the ponds were covered with ice.

Odour problems may in some instances be the most urgent reason for conversion to a mechanically aerated pond. However, the following factors are also in favour of the aerated pond over a straight facultative stabilization pond:

(i) Better land utilization through higher possible loadings in terms of persons per acre.

(ii) Improved sustained quality of the effluent during winter and spring months.

(iii) Less cost in sealing of ponds in porous soil because of less surface area.

7.2 Depth of pond

In the case of a straight facultative atabilization pond without aeration, the surface area exposed to solar radiation is the critical parameter and treatment capacity cannot be substantially increased by merely deepening the pond. This does not apply to mechanically aerated ponds in which case depths of 10 feet have been successfully employed (26) since the additional depth facilitates the introduction of certain aerator mechanisms which would otherwise not have been possible.

7.3 Sludge deposit

The aerated pond is not an activated sludge system (27). Whereas turbulence and mixing are desirable in an activated sludge tank in order that mixed liquor activated sludge should be kept in suspension, this procedure is detrimental to the operation of an aerated pond. Slow circulation in the aeration cells permits settling of solids and sludge in the bottom of the pond for anaerobic digestion.

7.4 Aeration facilities

Placing of the aerators or diffusers should be accomplished in such a way that the sludge layer is not disturbed. If a diffuser system is used, the diffusers should be mounted clear of this deposit to avoid turbulence.

The aeration facilities should be quite easily removable to allow overhaul and facilitate sludge removal, should this become necessary after a few years of operation.

To minimize turbulence and obtain highest efficiency, coarse bubble aeration should be avoided if possible.

7.5 Horsepower requirements

The control of bubble size, of rise rate and of laminar flow conditions will result in efficient utilization of horsepower: the air supplied is then employed for oxygenation of wastes rather than for rapid turnover of water to keep sludge in suspension. The horsepower requirements for aerating a mechanically aerated pond has been estimated at less than 0.006 h.p. per person. At 1 cent per kWh, the operating cost would be 48 cents per person per year.

7.6 Secondary ponds

Secondary ponds following a mechanically aerated primary pond should be designed in the normal way - see paragraph 4.4.

8. HEALTH ASPECTS

8.1 Impact on environmental health

The higher building and maintenance costs of conventional sewage purification plants and the highly skilled supervising staff required as well as the labour problem which follows in its wake, more often than not deter small municipalities and other communal authorities from installing a sewage reticulation system. If the economy resulting from the use of stabilization ponds could therefore be a factor in enabling a town to install water-borne sanitation at a much earlier stage than would otherwise be possible, environmental health would have benefitted. It has for instance been shown that septic tanks and french drains in an area where the top soil is shallow leads to a deterioration of streams flowing through these areas.

It has already been indicated that the contents of a primary stabilization pond is of a similar bacteriological quality to that of humus tank effluent. If, therefore, the introduction of a stabilization pond system brings about the disappearance of a large number of individual pit latrines, or septic tanks, or the trenching of night-soil and the associated regular and unhygienic removal of sanitary pails, then these facilities would have been exchanged for something infinitely more acceptable.

The same argument is put forward with reference to the aqua privy which, if it functions properly, has many attractive features and advantages such as economy, low water consumption, hygienic operation and simplicity of use, but which fell into disrepute for reasons described elsewhere(3). However, these units have been put to good use in combination with stabilization ponds to provide sanitary facilities for unsophisticated communities.

It is of interest that after a stabilization pond has been put into operation, the time required to fill such pond ensures that no effluent is discharged until such time as the biological associations have been well established and a good quality effluent has been ensured.

As far as virus removal is concerned, stabilization and maturation ponds seem to be greatly superior to conventional works, provided both systems are loaded only to design capacity. Malherbe and Strickland-Cholmley(28, 29) established that reovirus and enterovirus were not significantly affected by the conventional purification processes between raw sewage influent and secondary humus tank effluent, but in contrast only occasional low level reovirus and enterovirus isolations were made from maturation pond effluents. This may be of importance in view of the conflicting findings which have been reported on the efficacy of virus destruction in effluents by means of chlorination (30. 31, 32).

8.2 The rôle of birds

(a) Mechanical transmission of bacterial pathogens

It is conceivable that birds exposed to human faecal contamination might transport human pathogens mechanically to an impoundment reservoir but it is considered that the danger to human health would be slight because the water would provide an imperfect medium for bacterial growth. In this regard ponds present no greater source of contamination than would irrigation lands receiving sewage effluent or would biological filters, garbage heaps etc. to which birds may be attracted.

(b) Arthropod-borne viruses (Arboviruses)

Birds can act as reservoirs for arthropod-borne viruses which may be conveyed to man by mosquito vectors. It should be noted that the arboviruses are entirely distinct from the enteric viruses occurring in sewage, and are only transmitted to man by mosquitoes which have fed on infected birds. Birds attracted to bodies of water of any kind can act as arbovirus reservoirs, and the practical solution to this problem therefore lies in mosquito control.

8.3 Mosquito control

Apart from constituting a health hazard, though perhaps remote in South Africa, mosquitoes have a tremendous nuisance value and should not be allowed to breed freely in ponds.

Oil should not be poured on the surface of a pond as it would interfere with the transfer of oxygen from the atmosphere. However, in an emergency an insecticide could be sprayed in normal quantities round the perimeter of a pond without any serious deliterious effect.

The best control lies in the prevention of breeding taking place. This can best be achieved by keeping the pond clear of emergent and peripheral vegetation. Various investigators (33, 34, 35, 36) have found that under such circumstances no significant mosquito-breeding can take place. Emergent vegetation normally presents no problem in ponds of four feet or greater depth.

8.4 Bilharzia

Hodgson (37) investigated the snail vectors of Schistosomiasis in a pond in Rhodesia and found that the environment in an oxidation pond is not conducive to their propagation.

8.5 Parasites

The specific gravity of ova and cysts is approximately 1.1 (38), and it seems therefore that the long detention times in stabilization ponds cause their settlement. Over a year of observation on a pond series at Lusaka (39), no helminths, cysts or ova were found in the effluent from a series of stabilization ponds. Observations in Durban, Pretoria and Windhoek confirmed this.

8.6 Effect on the receiving water

The purification of raw sewage in stabilization ponds is not dependent on mechanical aids like pumps and distributors, and is consequently not affected by corrosion, mechanical faults and power failures. Shock loadings are absorbed much more effectively than in a conventional sewage purification plant. Using a MPN of faecal E. coli I as a yardstick, the bacteriological purification of a primary stabilization pond is of the same order as that obtained in a conventional sewage purification plant. As it is possible to place the design of the secondary ponds also on a rational basis and to calculate the number of ponds and the detention time in each necessary to produce an effluent of a reliable high quality, a stabilization pond system can be designed to achieve the same bacteriological purification obtainable in a conventional sewage works-maturation pond combination.

Although a faecal E. coli I count of nil per 100 ml cannot usually be obtained in maturation ponds, the degree of safety (as indicated by E. coli I count) that can be obtained is comparable with that attainable in practice where sand-filtered effluent is chlorinated (6). As a final safety barrier, maturation ponds offer better security. It is emphasized, however, that these results are unlikely to be attained unless the design requirements contained in this document have been met and the ponds are satisfactorily maintained at all times.

Various workers have reported that in cases where Mycobacterium tuberculosis was present in the raw sewage inflow, they have been unable to isolate this bacterium from a secondary stabilization or maturation pond(40) effluent, in the latter case even when 10 litre quantities were flocculated and the sediment investigated.

It seems reasonable that purified effluent destined for various purposes should comply with E. coli I limits related to these purposes. In this regard it is necessary to take cognisance of the extent to which all natural watercourses in Natal are polluted(41). Such background information puts the upper 97½ per cent confidence limit of 1000 E. coli I per 100 ml (see paragraph 3.3) in its true perspective:

Kemp et al(41) took 50 E. coli I/100 ml and a total plate count of 5000 per ml (5 days at 32°C) as the upper limits of a Class I water which, with only simple disinfection, should be suitable for drinking. It appears that only in the upper reaches of the Tugela River (near the Amphitheatre in Drakensberg) a water is to be found which, from a bacteriological angle, qualifies as a Class I water. It is also indicated that even if all known sources of pollution were eliminated, no additional rivers would be placed in Class I. In general, the rivers draining the rural areas of Natal qualify for Class II, i.e. these waters do not contain more than 1500 E. coli I per 100 ml and are suitable for drinking after conventional treatment.

9. CLIMATIC EFFECT

In the functioning of stabilization ponds, two mechanisms involving biological activity are at work. The primary one is that of bacterial metabolism and the degradation of organic matter with the release of gas and mineral elements. The second mechanism is that of algal metabolism producing sufficient oxygen to prevent anaerobic conditions of the whole body of water and thus restricting organic degradation. The process of oxygen production, through photosynthesis by algae, is dependent on the availability of carbon dioxide and the essential mineral elements and sufficiently high temperatures to allow prolific algal growth.

Light intensities are relatively high in South Africa, even during the winter season, and provided algae were present in sufficient numbers, photosynthetic activity in stabilization ponds would be maintained. The exception might be the Western Cape, where overcast weather can persist for several days at a time. Cold weather conditions, however, slow down algal development and in this way limit the permissible loading per unit of primary pond surface area.

Critical conditions also pertain in early spring when warmer weather sets in. Bacterial activity is accelerated and unstabilized sludge which had collected on the pond bottom during the preceding winter becomes subjected to more rapid degradation, thus increasing the demand placed on reoxygenation at a time when algal densities may still be low.

If pond loadings are such that algal development and the resultant photosynthetic activity can maintain aerobic surface conditions in a primary pond, then effluent stabilization is still quite effective even in winter. The amount of stabilization achieved in winter during experiments at Pretoria, using two ponds in series, is reflected by filtered BOD values in Table 4. The primary pond loading during these experiments was 145 lb BOD/acre/day.

Except for a period of approximately four months in winter when activity is at its lowest, algal activity is directly and indirectly responsible for a number of processes apart from merely maintaining aerobic conditions. As the algae are responsible for elevating the pH, some dissipation of ammonia is brought about, and by maintaining aerobic conditions, a process of nitrification (accompanied by denitrification in the sludge layer) is encouraged. Various nutrients are embodied in the cells of the algae, and if the algae are removed, the nutrient content of the effluent will accordingly be reduced.

TABLE 4

BOD AND NITROGEN ANALYSIS OF POND EFFLUENTS(22)

(All figures are in mg/litre)

Year 1961	Total BOD			Filtered BOD			Total nitrogen as N			NH_3-nitrogen as N			Filtered Kjeldahl nitrogen as N		
	A*	B	C	A	B	C	A	B	C	A	B	C	A	B	C
January	52	19	-	33	18	-	24	11.0	-	12.7	3.2	-	16.6	7.3	-
February	67	22	18	33	16	10	28	13.2	4.1	16.1	7.6	1.7	14.7	11.1	4.1
March	36	19	12	19	5	5	26	11.0	2.8	14.7	5.0	0.8	19.0	7.9	2.1
April	59	25	13	23	13	7	26	14.4	3.0	16.4	5.9	0.9	20.3	9.9	3.0
May	54	15	7	29	12	6	35	26.6	10.6	27.0	20.7	9.5	26.6	23.4	9.6
June	55	10	4	35	8	4	43	34.1	27.9	34.3	30.8	23.4	38.5	33.2	25.0
July	75	16	9	44	11	7	48	38.1	28.4	37.5	34.0	26.6	41.7	37.8	28.1
August	56	22	5	38	15	4	48	41.8	30.8	36.9	36.8	29.1	40.6	39.0	30.6
September	55	10	14	27	4	8	43	43.4	24.3	31.7	34.2	19.5	35.5	37.9	21.3
October	66	15	13	22	10	7	35	34.0	9.0	22.3	31.4	5.6	27.6	33.2	7.4
November	57	60**	21	22	6	15	26	42.0**	11.8	15.8	15.6	8.6	19.7	19.5	11.1
December	77	46**	21	9	5	7	31	27.7**	12.5	12.8	12.1	5.2	16.3	13.6	7.1
Annual mean	59	23	14	28	11	7		28.1	15.0	23.6	19.8	10.9	26.4	22.8	12.4

* Ponds A, B and C are in series

** Dense algal growth in Pond B

It therefore appears that as long as a pond remains aerobic, climatic changes have relatively little effect on effluent stabilization as measured by the filtered BOD. However, in summer enhanced algal activity, by elevating the pH, has a greatly beneficial effect on the quality of the effluent by reducing the ammonia nitrogen contents. This also holds good for phosphates which are precipitated at elevated pH values, but may be released again in winter when pH values drop.

10. EFFLUENT QUALITY

The quality of final effluents from the various types of pond systems will not prevent enrichment of a natural body of water, nor will it at all times comply in all respects with the requirements of the General Standards promulgated under the Water Act. More important, however, as viewed from an environmental health point of view, is the abatement of bacterial pollution and the improvement in sanitary conditions as effected by the installation of stabilization ponds in preference to septic tanks, french drain systems and night-soil disposal practices.

Similarly, maturation ponds which serve as a further treatment stage to the effluents from a conventional sewage works, bring about biological improvement, nutrient removal and reduction of the bacterial population in an open but controlled body of water. Where maturation ponds are not used, this task remains to be handled by public waters (rivers or lakes).

Furthermore, all pond systems have an excellent buffering capacity for balancing out excessive peak flows. Variations in quality of effluent are likely to be greater for a conventional system than for stabilization pond systems.

A performance schedule for the various types of pond systems constructed in accordance with the design criteria recommended in this document is given in Table 5.

TABLE 5

PERFORMANCE SCHEDULE FOR PONDS IN SOUTH AFRICA

The Table gives expected effluent qualities (showing maximum values) from stabilization ponds and maturation ponds constructed in accordance with recommended design criteria (not including algae floatation)

Parameter - In parts per million except where otherwise stated		Effluent Composition	
		Stabilization ponds	Maturation ponds
		For raw and settled sewage, septic tank and aqua-privy effluent	For well nitrified humus tank effluent
Colour, taste and odour		Not objectionable	Not objectionable
pH	(range)	7.0 - 10.5	7.0 - 10.5
Temperature °C	max.	30	30
Dissolved oxygen % sat.	min.	75	75
E. coli I	max.	1000/100 ml (97½% probability)	1000/100 ml (97½% probability)
Biochemical oxygen demand (BOD)	max.	20	15
BOD filtered	max.	15	10
Chemical oxygen demand (COD)	max.	250	130
Chemical oxygen demand (COD) soluble	max.	180	100
OA 4 hrs from $\frac{N}{80}$ $KMnO_4$ at 27°C (SABS)	max.	20	15
OA 4 hrs from $\frac{N}{80}$ $KMnO_4$ at 27°C (SABS) soluble	max.	10	10
Ammonia nitrogen	max.	35	10

It must be noted, however, that the schedule applies almost entirely to the treatment of domestic wastes. If any considerable quantity of industrial wastes are taken into the pond system of a sewage works, it cannot be expected that the pond effluents will necessarily show the performance as delineated in the schedule.

11. ALGAE REMOVAL

11.1 Desirability of algae removal

Sewage stabilization and effluent maturation in algal ponds provide the public health engineer with a low-cost and efficient means to facilitate the introduction of water-borne sanitation in many places where such a forward step to improve environmental health conditions would otherwise not have been possible. However, the presence of dense algal concentrations in pond effluents is a feature which in many instances renders the effluent unsuitable for reuse or discharge into a watercourse. In this regard it should be noted that the General Standards promulgated under Water Act No. 54 of 1956 lay down a maximum suspended solids concentration in an effluent of 25 mg/litre.

It therefore appears that if an economically feasible means of removing algae from a pond effluent could be developed, an important forward step would have been accomplished to establish stabilization ponds as an inexpensive and generally recognized means of sewage purification. However, it should be noted that high ammonia concentrations in winter also render ponds less acceptable since the General Standards stipulate a maximum ammonia-nitrogen concentration of 10 mg/litre.

Pilot plant work to study the feasibility of water reclamation from sewage effluent(42) has demonstrated vividly the important advantages to be derived from satisfactory algae removal from maturation pond effluents since the conventional water treatment process of flocculation/sedimentation followed by sand-filtration has proved quite inefficient.

The development of a successful method of algae removal would have the added advantage of providing a means for the possible harvesting of algae as a highly proteinaceous foodstuff.

11.2 Mechanism of algae removal

The most reliable method(43) consists in introducing small volumes of air together with the effluent at the suction side of a high speed centrifugal pump. If, however, this procedure causes the suction on the pump to be broken, an alternative would be to insert in the rising main an air-water emulsifier in front of which air is introduced. The air emulsifier, or special purpose pump, should be designed to produce very minute air bubbles evenly diffused in the stream of water passing through. The velocity of air-water emulsion in the rising main should exceed 7 feet per second to prevent separation.

11.3 Design criteria for floatation process of algae removal

For the most efficient utilization of aluminium sulphate or lime as flocculant, a retention period of 10 minutes is required for floc conditioning.

The tank(43) outlined in Fig. 4 incorporates a floc conditioning/ floatation compartment in the centre as well as a counter current/ floatation compartment of angular design around it. The flow arrangement shown in Fig. 5 incorporates an air-water emulsifier and chemical dosing apparatus.

11.4 Cost of floatation process

Apart from first costs, the floatation system designed to remove algae from maturation or stabilization pond effluents entails the following items which in turn would bring about certain running expenses:

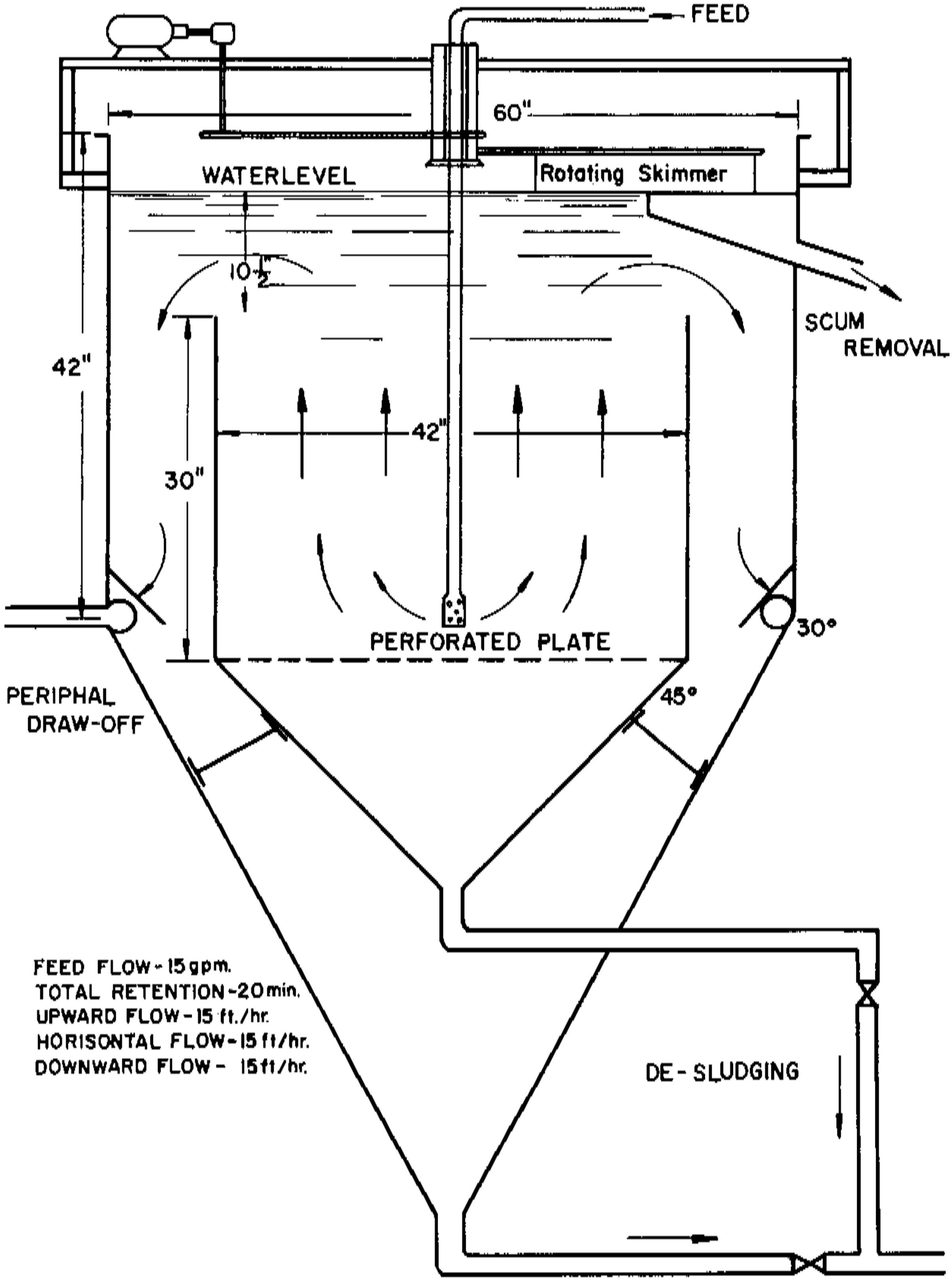

FIGURE 4
Flotation unit for maturation pond or humus tank effluents

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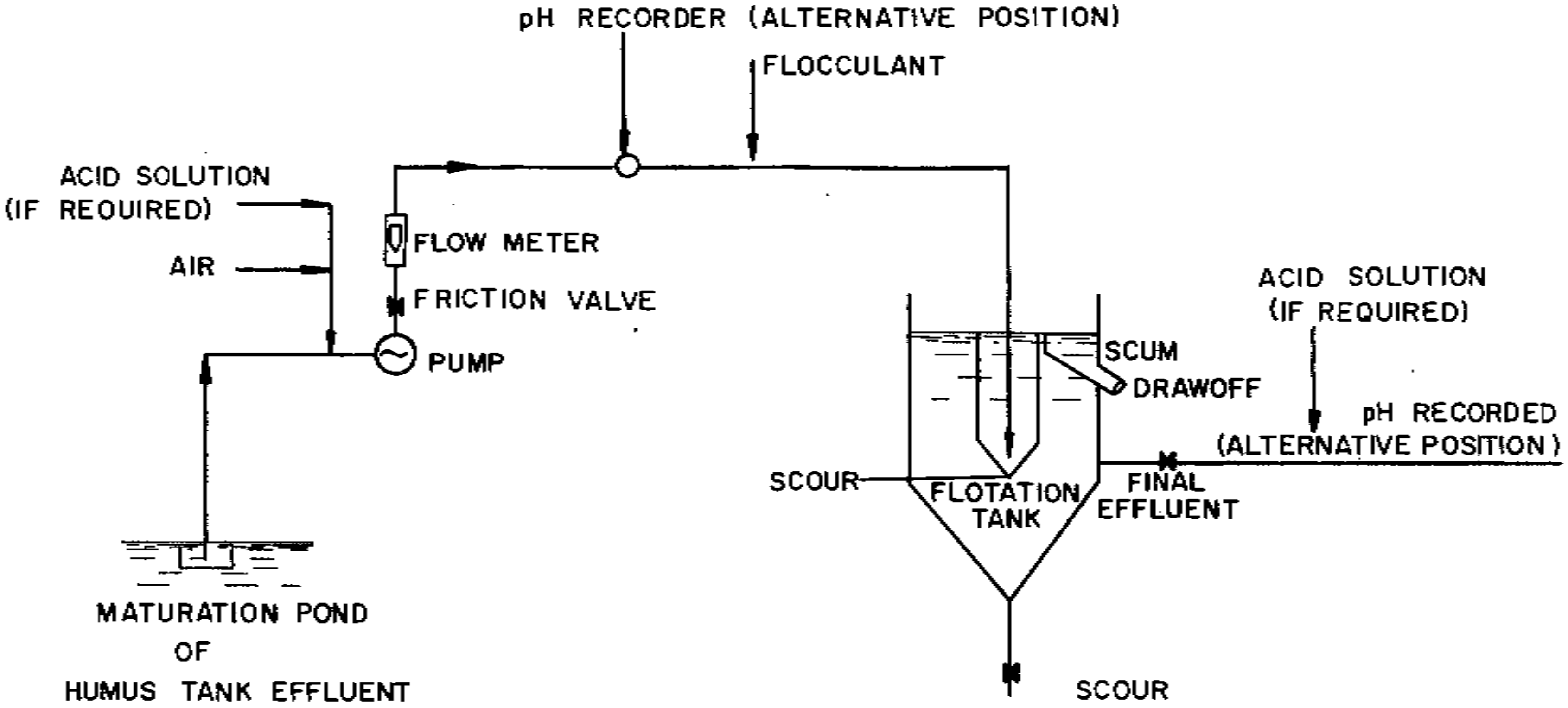

FIGURE 5

Flow diagram for flotation of maturation pond or humus tank effluents

pH-correction (by introducing a mineral acid or,
in special instances, carbon dioxide)

addition of flocculant (aluminium sulphate or lime)

electric power consumption

supervision and maintenance

The erection cost per capita of an algae floatation unit, complete with scum removal facilities, should be relatively small for schemes serving more than 5000 people (less than R2 per person). If, however, pH correction is brought about by the introduction of carbon dioxide, relatively expensive equipment would be required. pH-correction by means of carbon dioxide would normally, however, not be justified in small schemes of this nature, but only in large schemes where water reclamation is practised.

The cost of sulphuric acid (to obtain optimum pH) and aluminium sulphate (as flocculant) or lime (as flocculant) and sulphuric acid (for pH correction) would bring about a running expenditure of 5 to 7 cents per 1000 gallons of effluent treated. The cost of power would be small.

Maintenance by a part-time specialist to ensure satisfactory permance by the automatic pH controller, alum or lime feeder and system as a whole would add to the running costs of a scheme serving 5000 people to the extent of approximately 3 cents per 1000 gallons of effluent treated. Provision for labour requirements should be small since the same people employed on the upkeep of the stabilization ponds could be required to maintain and operate the sludge drying beds etc.

11.5 Effluent quality improvement resulting from floatation process

The improvement of stabilization pond and humus tank effluent by means of the floatation process is illustrated in Table 6.

TABLE 6

TYPICAL ANALYTICAL DATA OF STABILIZATION AND MATURATION POND AND HUMUS TANK EFFLUENTS BEFORE AND AFTER FLOCCULATION TREATMENT IN A FLOATATION UNIT (34)

Parameters mg/l	Stabilization Pond Effluent		Maturation Pond Effluent		Humus Tank Effluent	
	Before treatment	After treatment with 400 ppm Aluminium Sulphate	Before treatment	After treatment with 175 ppm Aluminium Sulphate	Before treatment	After treatment with 80 ppm Aluminium Sulphate
Total Dissolved Solids	500	750	500	620	500	560
Suspended Solids	280	85 *	55	30 *	25	35 *
COD (Chemical Oxygen Demand)	515	104	104	42	65	27
OA (Oxygen absorbed from $N/_{80}$ $KMnO_4$ in 4 hrs)	48	8.0	8.4	5.2	8.4	3.4
PO_4 (Total phosphates)	35.0	1.2	14.8	1.8	21.0	0.5
ABS (Syndets)	17.5	9.2	6.3	5.6	3.9	3.1
NH_3-N	20.7	16.4	4.9	4.2	12.3	9.5
Kjeldahl-N	53.8	17.1	10.8	6.7	16.7	9.1

* **Floc carry-over for removal by sand-filtration**

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