WORLD HEALTH ORGANIZATION
REGIONAL OFFICE
FOR THE EASTERN MEDITERRANEAN

ORGANISATION MONDIALE DE LA SANTE
BUREAU REGIONAL
POUR LA MEDITERRANEE ORIENTALE

SEMINAR ON SANITATION PROBLEMS
OF RAPID URBANIZATION

Lahore, 7-14 October 1971

EM/SEM.SAN.PROB.URB./11
27 August 1971
ENGLISH ONLY

OXIDATION PONDS

by

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I GENERAL

In Pakistan like in most other developing countries, migration of the people from rural to urban areas, particularly during the last two decades, has taken place at a very high rate. Rapid urbanization in these areas has resulted in a series of consequences which are prejudicial to health of the individual as well as to the community at large. These factors include the lack of adequate housing, clean drinking water supplies, effective disposal methods of domestic and industrial waste-waters and environmental sanitation facilities. While it is recognized that immediate measures are needed to safeguard the health of the people by the control and abatement of pollution, it is a fact that most of the communities in developing countries cannot generate enough funds for this purpose. The cost of construction as well as operation of the conventional methods of waste-water treatment are expensive, require skilled supervision and imported material and equipment. It is because of the prohibitive cost that not much work has been undertaken in the developing countries in respect of construction of sewage treatment plants. The choice of method or methods of safe disposal of sewage must be determined by economic consideration within the

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EMRO/71/1067

framework of sanitary needs. Oxidation pond method of waste-water treatment seems to provide the answer to many communities in these countries, whereas this method is simple, reliable and suited to local climatic conditions, it is also economical and therefore makes it possible for many communities to afford water-borne sewerage system with its related conveniences and benefits that would otherwise be impossible.

II DEFINITION

An oxidation pond is an engineered structure to utilize natural processes, under controlled conditions for the stabilization of organic wastes. The units are known by several names, i.e. sewage lagoons, oxidation ponds, stabilization ponds. The trend has been to accept the last nomenclature as the most fitting to the process.

Ponds which have been studied and developed may be classified into the following:

1. <u>Aerobic or "High-Rate" Ponds</u>

   In an aerobic pond all decomposition is carried out with the use of oxygen as a hydrogen acceptor. Oxidation and photosynthesis may be balanced to develop aerobic stabilization, and sometimes, a reclaimable excess of algae.

2. <u>Anaerobic Ponds</u>

   Decomposition in an anaerobic pond is carried out without the use of oxygen as ultimate hydrogen acceptor. Here anaerobic fermentation predominates.

3. <u>Facultative Ponds</u>

   In this type of pond, anaerobic fermentation, aerobic oxidation and photosynthesis reduction processes are going on simultaneously at varying rates.

The types of oxidation ponds and their respective characteristics are given below in Table I.

TABLE I

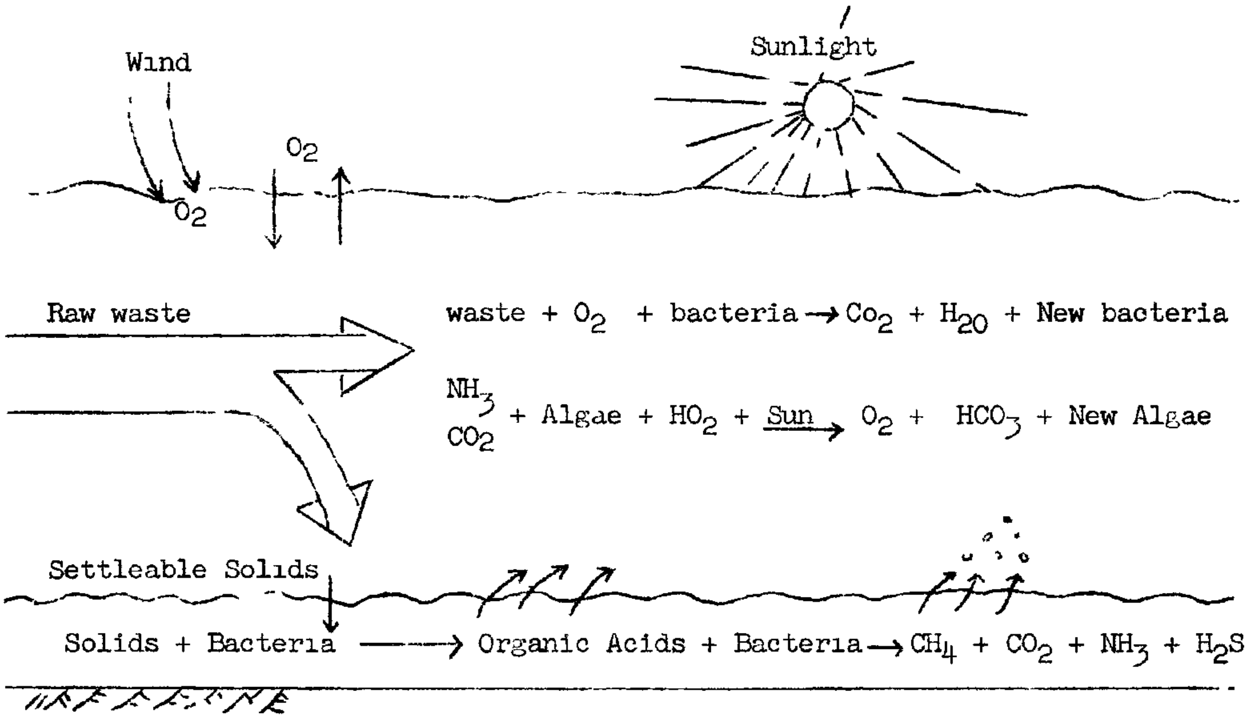
CHARACTERISTICS OF THREE TYPES OF OXIDATION PONDS

Pond Type	Requirements	Basis for Selection of Detention Period	Detention Period in Days	Basis for Depth Selection	Depth (feet)	Influent BOD (lbs/acre/day)	Effluent BOD (mg/l)
Aerobic	1. Light penetration to the bottom. 2. Mixing. 3. Turbidity control 4. Controlled growth of emergent vegetation	Most efficient use of sunlight	2-6	Penetration of light through active culture	0.6-1	100-200	20-30
Anaerobic	1. Small surface area to volume ratio 2. Controlled pH 3. Proper seed	1. Efficient land use. 2. Digestive period of prevailing temperature	30-50	1. Heat retention 2. Maintain anaerobic condition 3. Evaporation control	8-14	200-2000	100-1000
Facultative	1. May require seeding 2. Sludge blanket of several inches preferably at one location	1. Oxygen production 2. Bacterial die-away 3. Reaeration period	7-100	1. Amount of algae required 2. Weed control 3. Conditions for digestion near inlet	1-5	10-150	20-50

III MECHANISM OF TREATMENT

Many factors are involved in the waste stabilization mechanism, which begins immediately after waste enters the pond. Settleable solids, suspended solids and even colloidal particles are precipitated by the action of soluble salts, which are concentrated by evaporation. Decomposition of the settled organic matter produces an inert residue and soluble nutrients which diffuse into the overlying water. In anaerobic ponds the principal process involved is the decomposition of the settled organic solids under anaerobiosis.

In aerobic ponds, these nutrients along with light energy supply the requirements for photosynthesis by algae, which liberate the oxygen necessary to maintain an aerobic system. Algae play an important role in the overall stabilization process. The photosynthetic activity by the algae produces most of the oxygen in the aerobic ponds. Surface aeration too provides oxygen but it is very little as compared to the amount liberated by algae and the amount required for aerobic decomposition. The mechanism of purification which takes place in an oxidation pond is schematically shown below:



IV MICRO-ORGANISMS IN OXIDATION PONDS

The micro-organisms in oxidation ponds are the same as those existing in other treatment processes with the bacteria and algae predominating and protozoa and rotifers being present under certain loading conditions. The predomination of various species of micro-organisms will depend upon the loading factors and the physical design of the oxidation pond.

The predominant bacteria will be the Pseudomonas, flavo-bacterium and Alcaligenes. The phenomenon of die-off of coliform bacteria is due to the competition of the various micro-organisms for food and the high population of predatory protozoa and not due to the production of antibiotic by algae or other bacteria as has been suggested by some workers.

The algae predomination will depend upon the types and concentration of nutrients available. The phytoflagellates such as Euglena and Chlorella predominate in those areas where the nutrient level is quite high. The filamentous green algae appear where the nutrient level is low. Some of the common forms are Spirogyra, Vancheria and Ulothrix.

V COMPARISON OF SEWAGE TREATMENT METHODS

Mainly there are five methods of sewage treatment namely: activated sludge, trickling filters, Pasveer ditch, oxidation pond and direct ocean disposal. Ocean disposal is often the most economical but its use is limited by such limitations as the area's proximity to sea, public health, fisheries and aesthetic considerations. The choice between other methods largely depends on land requirements, construction, mechanical equipment cost, maintenance and operating costs. Reliability of the method and quality of the effluent produced as a result are the other factors which influence the decision of the public health engineering authorities.

1. Land Requirements

Activated sludge process has been adopted where land is very expensive whereas the biological filter method has been chosen where land is comparatively less costly. Oxidation ponds do require large areas of land but it must be emphasized that the land used for this method is reclaimable while this is not the case for other processes.

2. Construction and Maintenance Costs

The comparative capital and running costs of various conventional treatment plants as well as the oxidation pond for communities of population varying from 240 to 1 000 000 persons is given below in Table II. This shows that the cost per capita for sewage treatment increases sharply as the volume of the waste-water to be treated decreases. In spite of this, the operating and capital cost (1965 figures) of oxidation pond for a population of 1 000 000 persons was found to be only half than that of the conventional methods. For a lesser population of 30 000 persons the capital and running costs of oxidation pond as compared to other methods was 1/5 and 1/7 respectively. In a cost survey conducted over five states in America and covering a total of 260 plants of which 160 were oxidation ponds treating raw sewage, statistics showed that the cost of the latter was less than half the cost over a wide range of flows, of full secondary treatment, namely biological filters or activated sludge treatment. The cost of oxidation ponds over a wide range of flows was also less than that of primary treatment, that is for sedimentation only.

TABLE II

COST OF SEWAGE TREATMENT

Population	Capital Cost ($/person)		Running Costs/Year ($/person)	
	Conventional Purification Works (from the literature)	Stabilization Ponds without Sealing of Bottom (estimated)	Conventional Purification Works (from the literature)	Stabilization Ponds (estimated)
240	86.80	5.60	-	0.84
900	44.80	5.60	-	0.56
1 000	50.40	5.60	-	0.42
3 000	36.40	5.60	4.20	0.42
5 000	33.60	5.60	-	0.42
10 000	21.00	5.60	-	0.42
30 000	22.40	5.60	2.80	0.42
50 000	16.80	5.60	-	0.42
200 000	22.40	5.60	-	0.42
1 000 000	9.80	5.60	0.84	0.42

3. Reliability of the Process

Activated sludge process is liable to fail under shock loads, sludge building conditions, lack of supervision by skilled and qualified personnel. To a lesser extent this is also true for Pasveer ditch and trickling filter processes. Reported failure of a few oxidation ponds has been associated with very low temperatures only. The climatic conditions in the tropical countries, however, are ideal for the successful operation of the ponds provided these have been designed properly.

4. Quality of Effluent

The quality of effluent from conventional methods of treatment is such that they contain relatively high nitrates which stimulate undesirable algal growth in the receiving waters. The oxidation pond's algae-producing nutrients are largely used up by algal growth within the pond.

However, if improperly designed, the pond system too can give rise to effluent laden heavily by algae. As far as the bacteriological quality of effluent is concerned, it has been reported that the pond effluent quality measured in terms of MPN of faecal E-coli per ml with a value of 10 000 compares favourably with the effluent from humus tank with a value of 20 000.

From the above, it may be concluded that oxidation pond method is a suitable, cheap and reliable method of waste-water treatment and all communities, big and small, could adopt it to achieve the objective of providing sanitation and the abatement and control of pollution.

VI DESIGN CONSIDERATIONS

Important design features may be divided into two general categories, namely.

- Uncontrollable factors such as light, temperature, rain, wind and other climatological characteristics that effect the efficiency of the purification process.
- Controllable factors like size, depth, area loadings inlet and outlet devices, soil composition, site selection, method of operation, etc.

Let us discuss some of the important factors listed above.

1. Light

Light is the source of solar energy essential for photosynthesis - the primary source of oxygen in the aerobic stabilization pond. Two important variations in annual solar radiation, which differ with latitude, elevation and cloud cover will determine how stabilization pond will operate in a given location. Firstly, the seasonal changes in daily solar radiations will help to determine the seasonal rates of photosynthesis and the related oxygen production, and may give an indication of the seasonal difficulties to be expected. Secondly, the penetration of incident light determines how much of the pond volume will participate in oxygen production. This will have a direct bearing on the pond depth.

2. Temperature

In field observations, pond temperatures closely follow the air temperatures with the degree of fluctuation decreasing as the pond depth increases. This stabilizing effect on temperatures proves beneficial during the summer months. The depth of light penetration is greatest during the summer months - the period of highest water temperature. It is probable that very high pond temperatures (above 35°C) may favour the production of blue green algae which in turn may give rise to objectionable odours in the pond.

3. Wind

Normally, wave action is considered desirable to provide for surface aeration and mixing of dissolved oxygen through the liquid contents. Under conditions of favourable photosynthesis, however, surface agitation by light winds has been reported to lower the degree of dissolved oxygen supersaturation in the top layer of the pond's surface.

In general, winds of magnitude sufficient to induce wave action are advantageous. A disadvantage of wave action is in the danger of greater erosion of the shorelines or dykes surrounding the ponds. In practice, the pond layout should always be planned so that the direction of the prevailing wind is never along the line of flow. This results in short-circuiting sewage from inlet to outlet or retarding the normal flow.

4. Evaporation

Evaporation plays an important role in determining the level of the water maintained in an oxidation pond. The amount of evaporation at a given moment is dependent on the temperature, humidity and wind velocity. As a result it is difficult to predict with any accuracy the evaporation rate for any short period of time. Since the rate of evaporation in certain areas may be as high as 20 per cent of the influent it is necessary that field tests are made over a period of time under the local conditions.

5. Seepage

The problem of liquid loss by seepage into the soil is twofold. Firstly, there is the danger of polluting nearby water sources if the bottom of the pond is below or too near the water table at any season. Secondly, under severe conditions, the loss of the liquid may be great enough to drop the volume of the water retained to a point below that necessary for efficient aerobic operation. In order to determine the loss due to seepage, and the relative danger of pollution of any nearby water supply, percolation tests for the soils encountered should be carried out. It might, however, be noted that sludge deposits gradually seal the pond bottom reducing losses to a negligible point in relatively impervious soils.

6. Area and Loading

Surface area is one of the basic considerations in the design of oxidation ponds. It is customary to express pond loadings in population or preferably in pounds of BOD per acre of surface area. If aerobic conditions are to be maintained during all periods, the loadings will be governed by the oxygen production during periods of minimum algal activity and photosynthesis. Such a critical period can be expected to prevail in any location.

The normal range of design has been 20-50 lbs of BOD per acre per day in colder countries. In countries having similar climate as in Pakistan, heavier loadings up to 100-150 lbs of BOD per acre per day can be used.

7. Depth

On the basis of oxygen production, the optimum depth of the pond appears to be not greater than 2 feet. However, from a practical standpoint, the depth of liquids in oxidation ponds may generally range between 2 to 6 feet, with a minimum depth of 2 to 2 1/2 feet, to avoid growth of vegetation on the bottom of the pond. Shallower ponds (2 to 5 feet) are better in cool climates in order to allow for maximum penetration of sunlight. Because of the high angle of the sun in tropical climates, deeper sunlight penetration permits deeper ponds (3 to 6 feet).

8. Shape

Since an oxidation pond is essentially an earth structure the construction is of a simple nature and is reflected in the lower cost. The desirable shape for a pond is square or round, however, they can be shaped to fit the topography.

9. Site Selection

In order to minimize the possibility of complaints from possible objectionable odours from the ponds, it is suggested that the ponds should be located approximately 1/2 mile from a community and 1/4 mile from the nearest residence. These distances are not too different from those considered desirable in selection for conventional sewage treatment plants. Where possible, the pond site should be located leeward side of habitations. Consideration must be given to soil characteristics, proximity of ground water aquifers, and possibility of gravity flow to avoid pumping costs.

10. Pond Bottom

The pond bottom should essentially be level and should be free from vegetation when placed in operation. There may be some advantage in providing a slightly deeper area around the inlet to facilitate developing a depth of liquid that will promote algal growth in the early stages of operation. However this increased depth will be a disadvantage from the standpoint of reducing wind-induced currents for disposal of settleable solids, when the pond has reached its operating level.

11. Inlets and Outlets

In normal construction, the inlet to the pond is at the bottom and somewhere near the centre of the unit. This introduces a solid material near the bottom and allows wave action to distribute the material uniformly over the area. The outlet structure can be any simple overflow structure to handle the expected volumes.

12. Multiple Ponds

The flexibility of operation offered by multiple ponds appears to have certain advantages. With ponds designed to operate in parallel, it is possible to divert the entire flow to one pond when first placing the system in service, thereby reducing the lag period commonly experienced in developing a desirable liquid depth with weed control problem.

In raw sewage ponds operating in series, the settleable sewage solids will practically all be deposited in the first cell, therefore, the loading on this primary pond will be governed by the same criteria required to maintain aerobic conditions in a single pond system. Recirculation from a secondary pond may permit some increase in primary pond loading. Reducing individual pond size, made possible by multiple ponds will also reduce wind effects.

VII NEED FOR LOCAL RESEARCH

To properly evaluate the applicability of the oxidation pond process, it is essential to make a study of the performance of pilot or demonstration ponds under actual local conditions; that is, in relation to the climate, solation, groundwater hydrology, sewage characteristics, and other allied factors of the natural environment peculiar to a particular country. In spite of the basic research which has been done in United States and elsewhere, it is not possible, in the present state of the art, to design oxidation ponds on the basis of known sewage characteristics and environmental conditions. The data available from these foreign researches, although valuable in defining basic theory, cannot be used as design criteria for oxidation pond design in Pakistan as in other countries, without conducting field studies to show their applicability in the local environmental conditions.

VIII WORK AT ENGINEERING UNIVERSITY, LAHORE

A simple start to operate oxidation pond at the laboratory scale was made some two years ago in the Public Health Engineering Division of the Engineering University, Lahore, to establish some familiarity with the mechanics of the process and the data collected had demonstrated the treatability of locally produced wastes by this method. Bench-scale units, however, represent rather artificial conditions and results from these cannot be transferred into full-scale design criteria for actual operating units and conditions in the field. The work therefore has recently been extended to full-scale units treating domestic sewage which is mixed with a small quantity of industrial waste-water. It is the objective of this three-year long study to determine:

i. Performance under Pakistan conditions as judged by effluent quality.

ii. Efficiency as related to loading rate, solation and climatological variations.

iii. Effects of sewage influent quality and quantity variations.

iv. The most favourable loading rate for cities in Pakistan.

v. Optimum depth/area/volume design relationships.

vi. Acceptable design standards and operating control standards for West Pakistan.

In addition to the above primary objectives, the data acquired during the research will permit insight into basic biological phenomenon and interrelationships of the biota and biotic factors involved in this type of sewage treatment.

IX BASIC FEATURES OF EXPERIMENTAL PONDS

Four units of 1/4 acre each are being constructed on a site acquired by the Lahore Improvement Trust for construction of the treatment facilities of waste-water from Shadbagh area of Lahore. Each pond has a depth of 4 feet with a provision of increase by another 2 feet. The piping system is such that the ponds could be operated in parallel as well as in series. Provision in the design has been made for studying the effect of BOD loading of 50, 100, 150 and 200 lbs/acre/day. A laboratory is proposed to be constructed at the site for routine chemical and dissolved oxygen analyses. Arrangements have also been made to sample the ponds over cross-sectional transects (that is vertically and horizontally over the ponds) to evaluate the distribution of biochemical activity.

X NEW DEVELOPMENTS

1. Aerated Ponds

The low cost of oxidation ponds, free of any mechanical aids, is a factor which makes the system a very appealing one - particularly in developing countries and communities. However, where necessary and economically feasible, various means of artificial aeration can be used to induce circulation and wave action, and thus oxygen absorption. This means can be used to revive system which for some reasons have become anaerobic or to add capacity to existing facilities where the problem is immediate or where lack of funds or land delay the construction of additional ponds. It has been stated that it is possible to construct oxidation ponds as deep as 10 to 12 feet with loadings three to four times higher than those used in conventional ponds. Air requirements have been reported to be approximately 700 cubic feet per day per pound of BOD. The practicality of artificial aerated ponds, however, should not be over-estimated. An extended aeration process is no substitute for the natural treatment process using algae to provide oxygen. Therefore, wherever possible, oxidation ponds should be designed to function without artificial aeration.

2. High-Rate Oxidation Ponds

It has been said that oxidation ponds are not only suitable for developing countries, for the treatment of domestic and industrial sewage but the protein-rich algae grown on the pond could also be utilized, after due processing, for animal and even for human consumption. It is claimed that resources of protein could be augmented by utilizing the source of algae. To provide conditions for maximum yield of algae and reduction of sewage organic matter, high-rate oxidation ponds have been developed at the Universities of California and New South Wales. The ponds were made shallow (15 inches to 18 inches) to provide the sunshine necessary for algal growth throughout its depth. The detention time was short (1 day) which permits a high rate of reproduction and growth by means of an unlimited supply of algal nutrients. Since algae could become an exciting **new** source of protein to fill the food shortages of the future, let me briefly compare this method with conventional protein production methods.

Man has relied upon algae as a source of protein for centuries. In Japan, Philippines, China and Hawai, algae have been harvested from the continental shelf and eaten. Fish production represents a form of algal harvesting. The algae act as essential ingredients in the relatively insufficient food chain leading to the ultimate reclamation of waste nutrients in the form of fish protein. There has been frequent mention in the literature of the huge phytoplankton production of the ocean and the possibilities of direct harvest. However, at present, harvesting techniques are uneconomical. The greatest difficulty is centred on the minute size of the algal cells and their relatively low concentration in the marine environment. The commercial development of controlled algae farming on land, however, is technologically feasible.

Conventional crop yields are limited by the very nature of the plant itself. Nutrients must be absorbed from the soil and atmosphere. Relative to the algal cell the crop's absorbing surface to plant volume ratio is extremely small. Thus the photosynthetic energy conversion efficiency is normally limited to 0.5 per cent. On the other hand algae are not limited to lack of available nutrients and make use of their minute size to absorb nutrients and sunlight energy to grow and reproduce rapidly. The normal growth period for algae is one day in continuous mass algal culture. Rice produced on batch basis, requires three months for growth and is limited by nutrient supply and its dependence upon rainfall. The annual crop and algal protein yields are listed in Table III. The advantages of algal size and continuous growth process can be clearly seen. On an areal basis algae are 127 times more productive than soybean and 1460 times more productive than rice.

TABLE III

COMPARISON OF ALGAL PRODUCTION WITH CONVENTIONAL CROP YIELDS

Crop	Annual Protein Yield - lb/acre	Annual Consumptive Water Use - Acre ft per acre	lb of protein per acre foot of water
Soybean	576	2.0	288
Corn	240	2.0	120
Wheat	135	1.5	90
Rice	50	-	-
Algae	73 000	540*	135

* Consumptive waste-water use

A comparison has also been made in term of quality of protein or amino-acid content. The amino-acid contents of animal, vegetable and algal protein may be compared and are listed with FAO reference protein in Table IV.

TABLE IV

AMINO-ACID COMPOSITION OF ANIMAL, VEGETABLE AND ALGAL PROTEIN

(gm acid/100 gm protein)

Amino-Acid	FAO Reference	Algae*	Soybean	Egg	Beef
Histidine	2.4	1.6	2.9	2.4	3.5
Isoleusine	4.2	3.8	3.8	6.7	5.2
Leucine	4.8	7.5	7.3	8.8	8.2
Lysine	4.2	5.1	7.0	6.4	8.7
Methionine	2.2	1.5	1.6	3.1	2.5
Cystine	2.0	0.5	0.8	2.3	1.3
Phenylalanine	2.8	4.2	3.2	5.8	4.1
Tryptophan	1.4	1.0	1.9	1.7	1.2
Valine	4.2	5.7	4.4	7.4	5.6
Threonine	2.8	4.8	3.9	5.0	4.4
Arginine	2.0	6.5	6.3	6.5	6.5
Reference	(8)	(9)	(8)	(10)	(10)

* Algal sample consisting of sewage grown Scenedesmus and Chlorella - 48% protein.

It is seen that algae are similar to soybean in its protein quality and would complete with soybean particularly for chicken feed markets. These are but some of the points which clearly show the usefulness of algae as an excellent source of protein and which could be put to various uses depending upon the extent of its purification. Research work on this aspect is also proposed to be conducted at Engineering University's Research Pilot Plant after attaining the primary objectives of the project.

XI CONCLUSIONS

1. Oxidation ponds have been widely accepted in recent years, as a reliable method of waste-water treatment. Ponds have become an answer to the rising costs of sewage treatment for a great percentage of the communities in the developing countries because their construction and operating costs are very small as compared to the conventional methods of treatment.

2. Although many oxidation ponds have been constructed in various parts of the world, design criteria of this method remain empirical. Research studies should be undertaken to determine design criteria in the local conditions. Research work is also needed to establish deeper understanding of the phenomena associated with stabilization process.

3. Pilot-scale oxidation pond research project initiated at the West Pakistan University of Engineering and Technology, Lahore, could provide extremely useful information on design, operation and ecological aspects of the oxidation pond method.

4. Further investigations are needed to study the use of protein-rich algae for animal consumption. Possibilities should also be explored to process the algae for human consumption. For the protein-deficient developing countries this could become an exciting new source of protein.

ANNEX I

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