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GUIDELINES FOR THE MINIMUM EVALUATION OF THE PERFORMANCE OF FULL-SCALE WASTE STABILIZATION POND SYSTEMS

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Abstract—Guidelines are presented for the minimum evaluation of the performance of existing full-scale waste stabilization ponds. It is recommended that 24-h flow-weighted composite samples of the raw wastewater and pond effluents be taken over a 5 week period at the hottest and coldest periods of the year and analysed for BOD, COD, SS, NH_3–N, NO_3–N and total P; faecal coliform numbers should be determined on grab samples, and algal biomass estimated by measuring chlorophyll concentrations in samples of the pond water column. Pond mid-depth mean daily temperatures and pond sludge depths should also be measured, and local meteorological data obtained. The diurnal variation of pond effluent quality and of dissolved oxygen and temperature with depth should be measured at least once during each sampling season. Recommendations are also given for a more simplified estimate of pond performance in areas where the lack of skilled manpower, materials and equipment preclude the complete minimum evaluation procedure.

Key words—lagooning, performance, monitoring

INTRODUCTION

Waste stabilization ponds are frequently the wastewater treatment process of first choice in warm climates wherever land is available at reasonable cost (Arthur, 1983). Yet their design is often suboptimal since designers frequently use methods of design that are too conservative. This is not a criticism of design engineers, since they generally have no alternative as data from local ponds are either insufficient to permit a realistic assessment of pond performance or else they do not exist at all. Furthermore, past investigations on ponds have, for the most part, been carried out in temperate climates and the results so obtained are not directly applicable in tropical and semitropical zones. There is a great need, therefore, for reliable performance data from tropical pond systems.

The purpose of this paper is to present guidelines for the minimum evaluation of the performance of existing full-scale ponds so that the resulting data can be used by local design engineers with confidence. Such data, being usually obtained from suboptimally designed systems, are best used in conjunction with data from a regional pond research station, such as those in Campina Grande, Paraíba, Brazil (Silva, 1978; Mara *et al.* 1983), San Juan de Miraflores, Lima, Peru (Yanez, 1982; Bartone, 1985) and Frielas, Greater Lisbon, Portugal (Gomes de Sousa and do Nascimento, 1985). This is advisable since pond kinetics often appear to follow a retarded exponential model (Meron *et al.*, 1965; Arthur, 1981; Silva, 1983), and consequently a significant reduction in a pond's retention time does not necessarily produce a corresponding reduction in its performance.

The following guidelines are based on our experience with pond systems in many parts of the world over the last 20 years. We believe that they represent the minimum effort required to obtain a reasonable estimate of pond performance, and here we draw a clear distinction between programmes for pond effluent quality monitoring and those for pond performance assessment: the latter necessarily requires details of influent quality and quantity, in-pond biology and precise dimensional data, in addition to data on the effluent quality of each pond in the system. However, we recognize that in many areas of the developing world the technical manpower, equipment and materials required even for this may be partly or totally lacking; for such cases we indicate the absolute minimum that must be done in order to be able to gain even a limited estimate of pond performance.

PERFORMANCE EVALUATION

Physical description

A complete physical description of the pond system should be made. A comprehensive checklist is given in Appendix 1.

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Table 1. Parameters to be determined for minimum evaluation of pond performance

Parameters	To be determined for*	Type of sample†	Remarks
Flow	RW, FE	—	
BOD_5	RW, all pond effluents‡	C	Unfiltered and filtered samples
COD	RE, all pond effluents	C	Unfiltered and filtered samples
Suspended solids	RW, all pond effluents‡	C	
Faecal coliforms	RW, all pond effluents	G	
Chlorophyll-*a*	All F and M pond contents	P	
Algal genera	All F and M pond contents	P	
Ammonia	RW, all pond effluents‡	C	
Nitrate	RW, FE	C	
Chloride	RW, all pond effluents‡	—	
Total phosphorus	RW, FE	C	
Sulphide	RW, A pond effluents, F pond contents	G, P	Only if odour nuisance present or facultative pond effluent quality poor
pH	RW, all pond effluents	G	Sample at 0800–1000 and 1500–1700 h
Temperature	RW, all pond contents	—	Use max–min thermometers suspended in RW flow and at mid-depth in ponds
Sludge depth	A and F ponds	—	Use "white towel" test (Malan, 1964)
Electrical conductivity	FE	C	
Ca, Mg and Na	FE	C	Only if effluent used or to be
Boron	FE	C	used for crop irrigation. Ca, Mg
Intestinal nematode eggs§	FE	C	and Na required for SAR

*RW, raw wastewater; FE, final effluent of pond series; A, anaerobic; F, facultative; M, maturation.
†C, 24- h flow-weighted composite sample; G, grab sample taken when pond contents most homogenous; P, pond column sample.
‡Alternatively RW, A, F and final M pond effluents only, if more than 2 maturation ponds.
§*Ascaris*, *Trichuris* and the hookworms.

Sampling methodology

The use of correct techniques to obtain representative samples cannot be overemphasized. Too many attempted assessments of pond performance have been based on incorrect or dubious sampling methods, and they are, as a consequence, of virtually no use.

Types of sample. Most parameters should be measured on 24-h flow-weighted composite samples of the pond influence and effluent; but some, such as chlorophyll-*a*, need to be measured in samples of the entire pond water column; grab samples are required for pH and faecal coliforms; and others, such as mid-depth temperature and depth of the sludge layer, are measured in the pond itself. Table 1 gives a list of parameters whose values are required in a minimum evaluation exercise, together with notes on how they should be obtained. In areas with insufficient human and material resources, a minimum estimate of pond efficiency may be obtained by following the highly simplified procedure set out in Appendix 2.

The 24-h flow-weighted composite samples should be obtained in one of the following ways:

(a) in an automatic sampler which takes grab samples every hour, with subsequent manual flow-weighting (if this is not done automatically by the sampler);

(b) by taking grab samples manually every 1, 2 or at most 3 h (depending on labour availability), with subsequent manual flow-weighting.

If neither of these options is feasible, then grab samples should be taken every 2 or 3 h for as long a part of the day as possible and manually flow-weighted.

Samples must be properly preserved after collection (APHA, 1985). Usually storage below 4°C for a maximum of 30 h is adequate, although for certain parameters the analysis must be done sooner (for example, within 6 h for faecal coliforms).

Frequency of sampling. Samples should be collected during the most favourable and least favourable seasons of the year when pond performance (unless it is overloaded) is likely to be best and worst respectively; usually this means taking samples during the hottest and coldest months. However, in certain regions sampling may need to be done at three or four times in the year; for example, in parts of India samples should be taken at the peak of the hot dry season (March–June), the hot wet season (July–November) and the cool dry season (December–March).

Sampling should be done weekly during the 5-week period in the middle of each season selected for sampling. In order to take into account most of the weekly variation in influent and effluent quality the 24-h flow-weighted composite samples should each be taken on different days (e.g. on Monday in week 1, Tuesday in week 2 and so on). Alternatively the 24-h samples may be taken only in weeks 1, 3 and 5 (on Monday, Wednesday and Friday respectively, or Saturady, Monday and Wednesday in Islamic countries). Local factors, such as a high influx of tourists at weekends, may influence the choice of days on which samples are taken.

Flow measurement. An accurate measurement of the wastewater flow is essential: it is required not only for flow-weighting the composite samples, but also for determining the hydraulic mean retention times in, and organic loadings on, the ponds. The raw wastewater flow should be measured in a Parshall or

Venturi flume; any associated flow-recording instruments should have their calibration checked. If there is no flume, one must be installed for at least the sampling season (removable prefabricated flumes that can be inserted into the influent flow channel are commercially available in various sizes, or they can be easily made). The final effluent flow should be measured in a flume or a rectangular or vee-notch weir, whichever is most feasible.

Special techniques

Mean pond temperature. The mean of the daily maximum and minimum temperatures at the mid-depth of the pond is a close estimate (to within $<0.4°C$) of the mean daily pond temperature. A maximum-and-minimum thermometer should be suspended at the mid-depth of each pond by means of a polystyrene float and weight at 0800–0900 h and read 24 h later. This should be done each day samples are taken.

Chlorophyll-a. Algal biomass should be measured in terms of chlorophyll-*a* rather than algal numbers. This is not only because the associated laboratory work is easier and more precise (see Appendix 3), but also because of the large variation in size between common constituents of the algal flora—for example a large species of *Euglena* may have a volume some 3–4 times greater than smaller *Euglena* species or 85 times greater than pond *Chlorella* species—and because all algae contain essentially the same proportion of chlorophyll-*a*. This last statement is open to challenge by algal physiologists, but in our experience any differences in pigment content between species, or any changes within a single species or strain caused by environmental factors, do not significantly detract from the accuracy of biomass estimation by the chlorophyll methods, especially when compared with the inherent inaccuracies of alternative methods (Konig, 1983). It should be emphasized that the chlorophyll estimation technique is very easy to perform, especially by those accustomed to physico-chemical analyses of wastewater (who should not be persuaded by claims to the contrary). If there are no local facilities for chlorophyll estimation, then algal counts should be done; these should then be converted into biomass volumes as described in Appendix 3.

From the point of view of waste stabilization it is the quantity of algal biomass *in* the pond that is important, not that which it leaves in the effluent (which, as a result of algal stratification, varies considerably throughout a 24-h period). Thus samples of the entire pond water column should be obtained using the column sampler shown in Figs 1 and 2; five (or at least three) samples should be taken from different parts of the pond and thoroughly mixed together to provide a subsample for analysis. The samples may be obtained by boat or raft (for example, an inflatable dinghy equipped with oars, *not* an outboard motor which creates too much turbulence) or from a temporary sampling bridge (Fig. 3) which projects beyond the base of the pond embankment. If neither of these methods is feasible, a single column sample taken near the pond outlet may be taken instead.

Algal genera. A subsample (5–10 ml) from the composite pond column sample should be taken from microscopic examination to determine what algal genera are present, as this provides a good indication of the ecological status of a pond. If the sample cannot be examined immediately, it should be preserved with either 4% formalin or 0.7% Lugol's iodine. Ideally two subsamples should be taken and one preserved with formalin and the other with Lugol's iodine. The latter has the advantage of additionally acting as a cytological stain for starch granules and oligosaccarides, the location of which within the cell can aid identification. On the other hand the more natural coloration preserved by formalin in many cases makes general cytological observation easier.

Sludge depth. During each sampling season the depth of the sludge layer in anaerobic and primary facultative ponds should be measured by means of the "white towel test" (Malan, 1964). White towelling material is wrapped along one third the length of a rigid wooden pole (the pole dimensions are unimportant, but it must be rigid and obviously longer than the pond depth). The pole is then lowered into the pond, towel-end first and with care to keep it vertical, until it reaches the pond bottom; it is then slowly and carefully withdrawn (Fig. 4). The depth of the sludge layer is readily measured as the sludge–liquid interface is clearly visible, since some sludge particles will have been entrapped in the towelling material. The sludge depth should be measured at five points in the pond, away from the base of the embankments, and the mean depth calculated.

Special considerations

Sulphate and sulphide. Sulphate and sulphide measurements can provide useful information in some circumstances. For example, if odour is a problem, this is normally due to the anaerobic or primary facultative pond receiving too high a sulphate loading, either as a result of an elevated sulphate concentration in the raw wastewater or because it is receiving a higher organic load than it was designed to take. Sulphide levels in the raw wastewater indicate its degree of septicity, and in-pond sulphide concentrations in facultative ponds (determined on a subsample of the pond column samples taken for chlorophyll-*a* analysis) are useful in assessing the actual or potential toxicity to the pond algae and hence reduction in waste stabilization efficiency.

It is recommended therefore that the raw wastewater sulphate and sulphide concentrations and the anaerobic pond effluent and facultative in-pond sul-

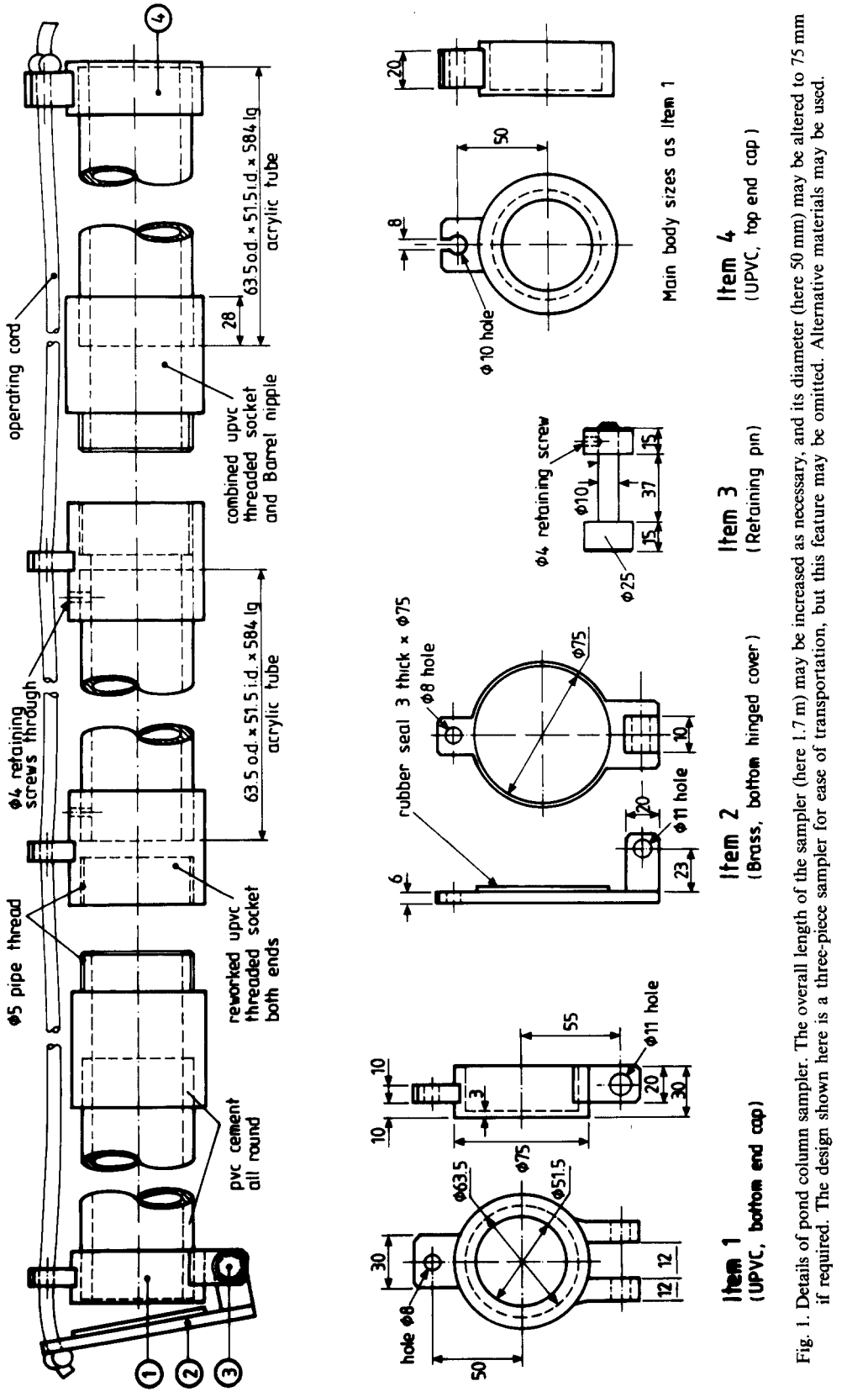

Fig. 1. Details of pond column sampler. The overall length of the sampler (here 1.7 m) may be increased as necessary, and its diameter (here 50 mm) may be altered to 75 mm if required. The design shown here is a three-piece sampler for ease of transportation, but this feature may be omitted. Alternative materials may be used.

Fig. 2. A 3-m pond column sampler in use at a pilot pond in northeast Brazil.

phide concentrations are measured when there is an odour problem, or when the facultative pond has a poor quality effluent ($BOD_5 > 100\,mg\,l^{-1}$) or a low in-pond chlorophyll-*a* concentration ($< 250\,\mu g\,l^{-1}$).

Dissolved oxygen and temperature profiles. The concentration of dissolved oxygen (DO) is often measured in pond effluent samples, but this does not provide any useful information on pond performance since it varies throughout the day as a result of algal activity. It is more meaningful to measure, at least once during each sampling season, the vertical distribution of DO and temperature (both can be measured with the same electrode). Profiles should be obtained at 0800, 1200 and 1600 h. If a DO/temperature electrode is not available, samples can be taken by means of a manually or electrically operated peristaltic pump and tube system which allows samples to be drawn from the appropriate depth into bottles at the surface. The pump should be operated for several minutes to flush out the tubing and sample bottles; this ensures that the sample collected comes from the required depth and that it does not come in contact with air, which would otherwise significantly alter its DO concentration. (This last point militates against the practice of lowering an empty corked sample bottle to the required depth and then releasing the cork to allow the bottle to fill.) Winkler analysis is then used to determine the DO concentration in these sample bottles.

Effluent reuse. If the final effluent of the pond series is being used or considered for crop irrigation, additional parameters should be measured. These include electrical conductivity; sodium, calcium and magnesium, in order to calculate the sodium absorption ratio; boron; and intestinal nematode eggs (IRCWD, 1985). If significant quantities of industrial wastewater are treated in the ponds, the final effluent

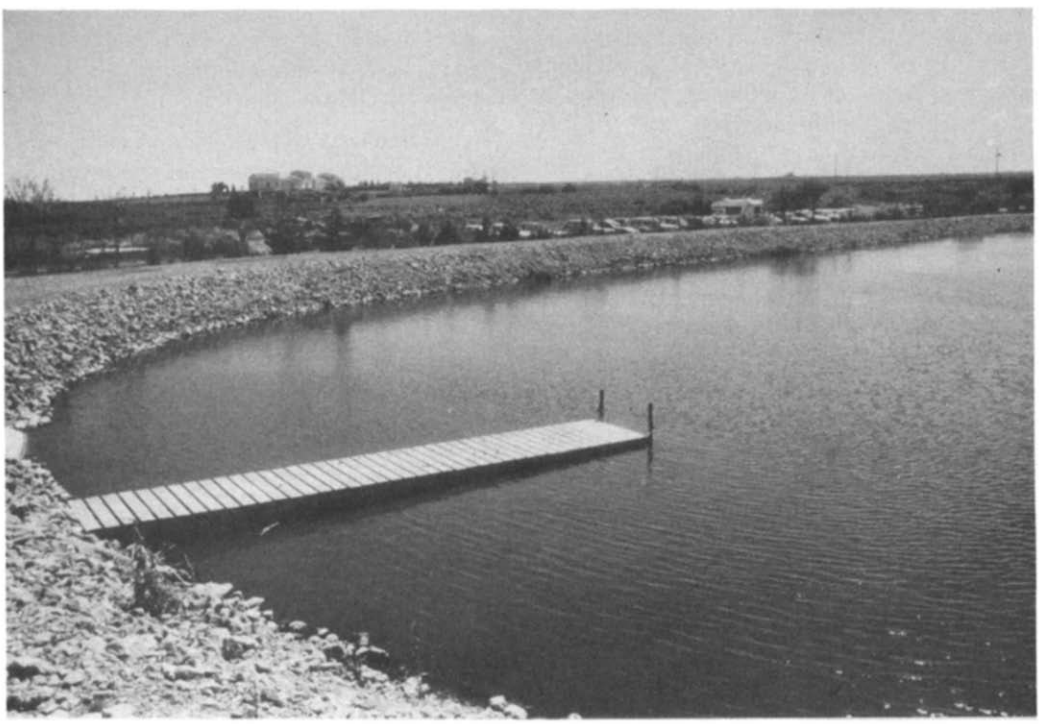

Fig. 3. Wooden sampling bridge extending beyond the embankment base at a pond in southern France.

Fig. 4. Measurement of sludge depth in a facultative pond in Peru using the "white towel test".

should also be analysed for the appropriate heavy metals. All these additional parameters can be measured on the 24-h flow-weighted composite samples.

Analytical procedures

The procedures described in the current edition of *Standard Methods* (APHA, 1985) are generally recommended. In certain cases we depart from *Standard Methods*: for example, we use lauryl sulphate broth (Stanfield and Irving, 1981) solidified with agar for counting faecal coliforms; and szechrome NAS (diphenylamine sulponic acid chromogene) reagent (Gammatest Materials Testing Ltd, Beer Sheva, Israel) for the spectrophotometric determination of nitrate at 570 nm; the methanol extraction technique described by Pearson (1986) (see Appendix 3) for the estimation of chlorophyll-*a* in pond samples; and the method of Mara and Silva (1986) for counting intestinal nematode eggs.

Metereological data

Data on maximum and minimum air temperatures, rainfall and evaporation, and wind speed and direction should be obtained from the nearest meteorological station (which should ideally be no more than 10 km distant from the ponds); these data are in any case, needed to determine the appropriate sampling seasons. Additional data (for example, on relative humidity, sunshine hours, solar radiation intensity) should be obtained if they are available. If the nearest meteorological station is more than 10 km distant, it will be necessary (and a sensible precaution even if it is not) to measure at least daily maximum and minimum air temperatures, rainfall and evaporation (and other parameters if the appropriate instruments are available) at the pond site during each sampling season.

Data analysis and storage

Mean values should be calculated for the parameters in each sampling season. Values, based on these means, for the following parameters should then be calculated:

(a) hydraulic mean retention time (=volume/flow) in each pond and each series of ponds (d);

(b) volumetric BOD_5 and COD loading rates on anaerobic ponds (if any) (g or $kg\,m^{-3}\,d^{-1}$);

(c) surface BOD_5 and COD loading rates on facultative pond ($kg\,ha^{-1}\,d^{-1}$); and

(d) percentage removals of BOD_5, COD, SS and NH_3–N, and $\log_{10}$ unit reduction of FC, in each pond and each series of ponds.

A simple kinetic analysis, based on (for example) a first order reaction in a completely mixed or plug flow reactor (for length to breadth ratios less or greater than 4 respectivley), may be attempted if desired.

Finally, the responsible local or central governmental agency should record and store all the information and data collected from the pond complex, together with an adequate description of precisely how they were obtained, in such a way that design engineers and research workers can have ready access to them. If there is a local regional pond research station, or other appropriate research and/or infor-

mation agency, it would be prudent for the data to be deposited there as well.

CONCLUSION

We wish to reiterate that the sampling schedule recommended herein has been designed to provide the minimum data which, in our opinion, are necessary for the evaluation of the behaviour and performance of existing full-scale pond systems. Such an evaluation is necessary if local pond design procedures are to be optimized in order to reduce pond construction costs. The data required for this purpose should not be confused with merely obtaining data on basic final effluent quality since, although such knowledge is important, it cannot by itself provide any information of use in correcting any system malfunction, nor can it help identify how close the system might be to its optimal operating conditions.

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APPENDIX 1

Physical Description of Pond Complexes

A physical description of the pond complex for which a minimum evaluation of performance is being carried out should include the following:

1. *Location*

1.1 Latitude and longitude (or national map reference).
1.2 Altitude.
1.3 Geographical description.
1.4 City or industry served (population or population equivalent calculated at 50 g BOD_5 $caput^{-1}$ d^{-1}; proportion and type of industrial effluents).
1.5 Climatic data (annual and monthy means; name and location of nearest meteorological station).

2. *Pond complex*

2.1 Number of ponds and their arrangement in series and parallel (flexibility of interpond pipework; facilities for interpond recirculation).
2.2 Types of ponds (anaerobic, facultative, maturation, floating and/or rooted macrophyte, polishing, high-rate, aerated).
2.3 Pretreatment facilities (screening, comminution, grit removal, primary sedimentation, activated sludge/biofiltration).
2.4 Flow measurement facilities.
2.5 Post-treatment facilities (algal removal, chlorination).
2.6 Destination of final effluent (surface water discharge, groundwater recharge, crop irrigation, fish ponds).
2.7 History (when built and commissioned; subsequent modifications).

3. *Individual ponds*

3.1 Dimensions (length, breadth at pond base and water surface; water depth; freeboard; embankment slope).
3.2 Pond lining (if any).
3.3 Embankment protection at top water level (evidence of erosion).
3.4 Inlet and outlet structures (discharge above/below top water level; scum guards; outlet take-off depth—fixed or variable).
3.5 Special features.
3.6 Design flows and organic loadings; actual flows and loadings; trends.
3.7 Existing data on influent and effluent quality (type of samples, when taken).

Maps and engineering drawings, if available, or sketches should also be kept in the pond description file.

APPENDIX 2

Minimum Estimate of Pond Performance

In areas where there is a lack of the required technical manpower and/or the equipment and materials necessary to undertake the minimum evaluation procedure recommended above, some estimate of pond performance can be obtained in the following manner:

(1) Determine the most critical season for pond performance (this will normally be during the coldest month).
(2) If necessary, install a flow-measuring flume in the raw wastewater inlet channel.
(3) On the Tuesday and Thursday (on Sunday and Tuesday in Islamic countries) of one week during this period take grab samples of the raw wastewater and each pond effluent every 3 h and manually flow-weight them to provide 24-h composite samples. Determine the average daily flows.
(4) Determine the values of the following parameters in the samples specified:
   (a) unfiltered BOD_5 [24-h composite samples (CS) of raw wastewater (RW) and final effluent (FE)];
   (b) unfiltered COD (CS or RW and all effluents (AE)];
   (c) SS (CS of RW amd FE);
   (d) pH (grab samples (GS) of RW and AE taken at 0800–1000 h and 1400–1600 h);
   (e) chlorophyll-*a* (in-pond column samples of all facultative and maturation ponds);
   (f) faecal coliforms (GS of RW and AE taken at 0800–1000 h or within 2–4 h of sunrise);
   (g) DO at 10 cm depth at 1600 h in facultative ponds;
   (h) Mean daily raw wastewater and mid-depth pond temperatures; and
   (i) sludge depth in anaerobic and facultative ponds.

APPENDIX 3

Estimation of Chlorophyll-a

The technique described herein for the laboratory determination of chlorophyll-*a* involves filtration of a pond column subsample to collect the algae on a filter, from which the chlorophyll is extracted into an organic solvent prior to spectrophotometric analysis. The procedure detailed below is not the most sophisticated available, but in our experience represents a good compromise between accuracy and ease of determination, especially in the field.

Materials and equipment

(a) 1% (w/v) aqueous suspension of $MgCO_3$;
(b) 90% (v/v) aqueous methanol;
(c) 25 mm glass fiber filter papers (e.g. Whatman GF/C);
(d) compatible filtration system (e.g. Whatman 1960 032 with a 250–1000 ml filter flask) and vacuum source;
(e) simple spectrophotometer (663 and 750 nm);
(f) small bench centrifuge (500 *g*).

Different sized filter papers may be used, and if glass fiber filter papers are not available a good quality general purpose paper (e.g. Whatman grade 2) may be used. The centrifuge is not essential, but improves the spectrophotometry by removing any turbidity present.

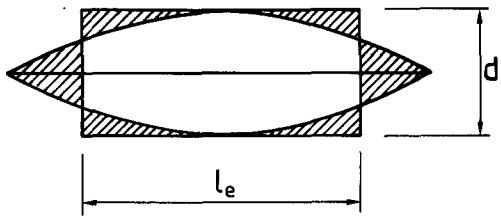

Fig. A1. Conversion of *Euglena* to an equivalent cylinder.

Method

(1) Filter 2.5 ml of the $MgCO_3$ suspension (this aids retention of the algae and maintains alkaline conditions to prevent denaturation of the chlorophyll during extraction).

(2) Filter a known volume (at least 10 ml and preferably close to 50 ml) of well-stirred pond column subsample.

(3) Place the filter paper in a glass test tube and add 10 ml of 90% methanol. Boil for 2 min to extract the chlorophyll (the solvent boils at ~65°C, so it can be boiled in a hot water bath). The filter paper should become white; if it does not, macerate it with a glass rod to aid extraction.

(4) If a centrifuge is available, centrifuge the extract at 500 *g* for 10 min. Otherwise leave the extract for 15 min in the dark to allow most of the debris to settle out.

(5) Make up the extract volume to exactly 10 ml by adding 90% methanol, and transfer a portion of the extract to a 1 cm cuvette.

(6) Set the wavelength on the spectrophotometer to 663 nm (or 665 nm if calibrated in 5 nm divisions). Zero with 90% methanol, and read the absorbance of the chlorophyll extract (the absorbance should be between 0.2 and 0.8: if it is less, re-extract using a larger sample volume; if more, dilute with a known volume of methanol). Set the wavelength to 750 nm, re-zero and read the absorbance of the extract (this corrects for turbidity by measuring non-specific absorbance).

(7) Calculate the concentration of chlorophyll-*a* from:

$$\text{Chl-}a\ (\mu g\, l^{-1}) = \frac{(OD_{663} - D_{750})}{77} \times \frac{\text{(solvent extract volume, ml)}}{\text{(original sample volume, ml)}} \times 10^6$$

where OD_{663} and OD_{750} are the absorbance readings at 663 and 750 nm. The figure of 77 is the extinction coefficient for chlorophyll-*a* in 90% methanol in $1\,g^{-1}\,cm^{-1}$. If the path length of the cuvette used is not 1 cm, then the absorbance difference should be divided by the path length in cm.

(8) Pond samples should not be stored prior to analysis for longer than 6 h. In the field the best stage for storage is after filtration. The filter papers should be dried in the dark at as low a temperature as possible (preferably 4°C). If they are then kept in the dark (e.g. wrapped in foil), they

Table A1. Typical mean cell dimensions and volumes for some major pond algae in northeast Brazil*

Alga	Shape	Geometric formula	Mean cell dimensions (μm)†	Mean cell volume (μm^3)
Euglena‡—short form	Cylinder	$\frac{1}{4}\pi\, d^2\, l_e$	$d = 11.0 \quad l_e = 103$	9788
long form	Cylinder	$\frac{1}{4}\pi\, d^2\, l_e$	$d = 7.0 \quad l_e = 66$	2557
Pyrobotrys—individual cell	Ellipsoid	$\frac{1}{6}\pi$ abc	$a = b = 6.0 \quad c = 9.7$	183
16-cell colony§				2925
Chlamydomonas	Ellipsoid	$\frac{1}{6}\pi$ abc	$a = b = 6.0 \quad c = 8.5$	160
Chlorella	Sphere	$\frac{1}{6}\pi\, d^3$	$d = 6.0$	113

*From Konig (1983).
†Based on measurements of 100 cells of each alga.
‡The two forms of *Euglena* were present in equal proportions. The dimension l_e is defined in Fig. A1.
§*Pyrobotrys* colonies contained 8, 16 or 32 cells, but most commonly 16.

may be stored for several weeks prior to spectrophotometric analysis with a maximum absorbance loss of 10%.

(9) Acetone (90% in water) may be used, but chlorophyll extraction from certain algae (e.g. *Chlorella*) is much less efficient than with methanol. The acetone must be ice-cold and extraction should be done in a refrigerator for 6 h. The extinction coefficient for 90% acetone is $89\,l\,g^{-1}\,cm^{-1}$.

Conversion of Algal Counts to Algal Volumes

In the absence of facilities for measuring chlorophyll-*a* concentrations, standard algal counts should be made (APHA, 1985) and then converted into biomass volumes in order to take into account the large differences in size between different pond algae. This volume conversion process requires knowledge of the geometric shape and dimensions of the predominant pond algae; Table A1 gives these and the corresponding volumes for *Euglena*, *Pyrobotrys*, *Chlamydomonas* and *Chlorella*, which were found to predominate in facultative and maturation ponds in northeast Brazil (Konig, 1983); the volume of *Euglena* was calculated on the basis of its estimated equivalent cylindrical length as shown in Fig. A1.