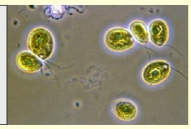
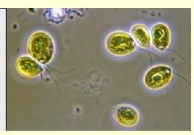
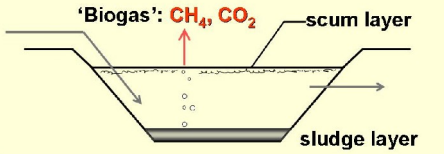
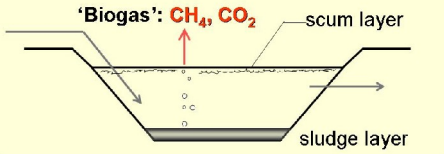
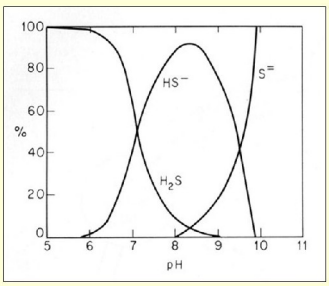
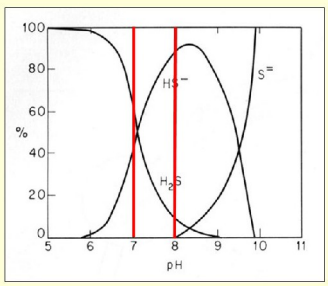
WASTE STABILIZATION PONDS 3
Anaerobic ponds

1.	 Natural Wastewater Treatment & Reuse **ANAEROBIC PONDS** Professor Mara	In this presentation we're going to look at the design and performance of anaerobic ponds.
2.	**ANAEROBIC PONDS** • high organic (BOD) loading → devoid of dissolved oxygen • depth range 1–5 m; depends on ground conditions – usually 2–4 m • no (or very few) algae → surface area not important	These ponds have such a high organic loading, or BOD loading, that they do not contain any dissolved oxygen. They're usually quite deep, often 2−4 m deep. And they contain no, or very few, algae, although …
3.	ALGAE: occasional surface film of sulphide-tolerant *Chlamydomonas* 	we occasionally come across a thin surface film of *Chlamadomonas*, which is a sulphide-resistant alga.
4.	ALGAE: occasional surface film of sulphide-tolerant *Chlamydomonas*  OPERATION OF ANAEROBIC PONDS • sedimentation of settleable solids and • intense anaerobic digestion (>15°C) and copious 'biogas' (CH_4 & CO_2) production • high BOD & SS removal • functions much like an open septic tank	The operation of anaerobic ponds is quite straightforward: the settleable solids settle out to form a sludge layer and, especially at temperatures above 15°C, there is intense anaerobic digestion in the sludge layer and a lot of biogas, methane & carbon dioxide, is produced. In warm climates the removals of BOD and suspended solids are both very high. In general terms, an anaerobic pond functions much like an open septic tank.

5.	 About 30% of influent BOD leaves as biogas	Often around 30% of the influent BOD leaves the pond as biogas, CH_4 & CO_2.
6.	 About 30% of influent BOD leaves as biogas ▪ same groups of anaerobic bacteria involved as in septic tanks and anaerobic digesters → require same environmental conditions (eg, pH >6.5)	There are the same groups of anaerobic organisms in anaerobic ponds as in other anaerobic reactors, like septic tanks and anaerobic digesters; and they require the same environmental conditions, such as a pH above 6.5.
7.	DESIGN OF ANAEROBIC PONDS based on volumetric BOD_5 loading, λ_v $\lambda_V = L_i Q/V$ g/m³d $= L_i/\theta_a$ L_i = influent BOD_5 mg/l (= g/m³) Q = flow, m³/d V = volume, m³ V/Q = θ (retention time, days) $\theta_a \geq 1$ d	We design anaerobic ponds on the basis of volumetric BOD loading, λ_v which is expressed in units of g/m^3 day. So, if L_i is the influent BOD in mg/l (which is the same as g/m^3), Q is the flow in m^3/day and V is the volume in m^3, then: $\lambda_v = L_i Q/V$ or, since V/Q is the mean hydraulic retention time θ_a, $\lambda_v = L_i/\theta_a$ The value of θ_a should not be less than 1 day.
8.	• Design range for normal domestic wastewater: $100 \leq \lambda_V \leq 400$ – if <100, then not fully anaerobic (?) – if >400, then risk of odour release	The usual range of design values for λ_v on anaerobic ponds treating normal domestic and municipal wastewater is 100−400 g/m^3 day. It's generally thought that if λ_v is less than 100, the pond won't be fully anaerobic, but I'm not sure if this is really true. And, if λ_v is more than 400, then there's a risk of odour release.

9.	**ODOUR** • caused mainly by hydrogen sulphide gas (H_2S) • sulphates (SO_4^{2-}) reduced in anaerobic ponds by obligately anaerobic sulphate-reducing bacteria (eg, *Desulfovibrio* spp) to sulphides (H_2S, HS^-, S^{2-}) • proportion of sulphide existing as H_2S depends on pH:	So we need to understand odour. It's mainly caused by H_2S, and this comes from the reduction of sulphates by the obligately anaerobic sulphate-reducing bacteria, such as *Desulfovibrio* spp. These bacteria reduce sulphates to sulphides, and in aqueous solution sulphides are present as a mixture of dissolved H_2S gas molecules, bisulphide ions HS^-, and sulphide ions S^{2-}; and the proportion of these three forms depends on the pH,
10.	 Effect of pH on hydrogen sulphide–bisulphide–sulphide equilibrium	as shown in this slide. We can see immediately that the sulphide ions (S^{2-}) only begin to appear at a pH of 8, so we won't find them in an anaerobic pond.
11.	 Effect of pH on hydrogen sulphide–bisulphide–sulphide equilibrium	The two red lines are at pH 7 and pH 8, and anaerobic ponds usually have a pH between these two values. At pH 7 roughly half the total sulphide is present as H_2S and half as HS^-, but at pH 8 only around 10% is H_2S and 90% is HS^-. The more H_2S there is, the greater the risk of odour, because odour is caused by the H_2S molecules that leave the pond through its surface as they seek to increase the partial pressure of H_2S in the air above the pond – in other words, as they seek to obey Henry's Law.
12.	Odour, continued • odour not usually a problem if sulphate concentration <500 mg/l as SO_4^{2-} ❖ check the sulphate conc. of the local drinking water (max = 250 mg/l) • control therefore not normally necessary, but can be achieved by adding lime or soda ash to keep pH >7 (or by recirculating maturation pond effluent, but expensive and pump needs maintenance)	Early work in the US showed that anaerobic ponds did not have an odour problem if the sulphate concentration in the raw wastewater was less than 500 mg SO_4/l. This is quite high, especially as the maximum concentration permitted in drinking water is 250 mg SO_4/l. Of course, the sulphate concentration in wastewater is higher than in drinking water as detergents, for example, can contain up to 40% by weight of sodium sulphate. Control should not normally be necessary but, if it is required, you can add lime or soda ash to keep the pH above 7.

13.

Recommended Design Procedure for Anaerobic Ponds

- Performance should increase with temperature, but insufficient reliable field data available to develop good design equation
- **Design temperature: mean air temp. in coldest month (slightly conservative as pond temp. some 2–3°C warmer)**
- **Minimum retention time of 1 day**

As for the design of anaerobic ponds, we know that performance increases with temperature; but there are too few good-quality field data to derive a satisfactory design equation relating λ_v with temperature.

The design temperature we use is the mean temperature of the coldest month, and we generally adopt a minimum value for the retention time of 1 day.

14.

DESIGN VALUES

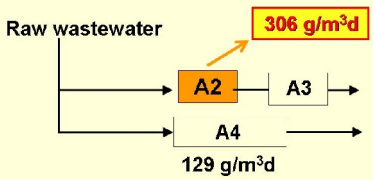
Temp (°C)	BOD_5 loading (g/m^3 day)	Percentage BOD removal
≤10	100	40
10–20	20T – 100*	2T + 20*
20–25	10T + 100*	2T + 20*
>25	350	70

* Linear interpolation (T = temperature, °C)

This table gives the design values of λ_v. They are: 100 g/m^3 day at 10°C and below; 200 at 15°C; 300 at 20°C; and 350 at 25°C, with linear interpolation in between. The BOD removals that we assume in our design are 40% at 10°C and below; 50% at 15°C; 60% at 20°C; and 70% at 25°C, again with linear interpolation in between.

15.

PERFORMANCE OF ANAEROBIC PONDS



❖ Northeast Brazil, ~25 °C

This is some work we did with anaerobic ponds in northeast Brazil some 25 years ago, when in fact it was the first work done on anaerobic ponds anywhere in the country.

We had two anaerobic ponds in series, coded A2 and A3, and in parallel with these was another anaerobic pond, A4.

The pond temperature was around 25°C throughout the year, and the loading on A2[*] was just over 300 g/m^3 day and on A4 just under 130 g/m^3 day.

16.

	Retention time (days)	BOD_5 (mg/l)	SS (mg/l)	FC (per 100 ml)
Raw w'w	–	245	310	4.7×10^7
A2	0.8	59*	82**	8.1×10^6
A3¶	0.4	45	64	5.0×10^6
A4	1.9	49	57	4.7×10^6

* 76 percent removal ** 74 percent removal

¶ Not worth having (at least for domestic w'w)

These were the results. Pond A2,[*] which had a retention time of 0.8 day, reduced the BOD from 245 mg/l to 59 mg/l, that's a removal of nearly 76%. The other ponds didn't perform as well; and the whole set of results from these and other anaerobic ponds at the same site …

[*] *There's an error on the audio track for slides 15 & 16: Pond A3 is referred to, but the reference should be to Pond A2.*

17.

Performance of Anaerobic Ponds
Northeast Brazil 25°C

Pond Code	Retention time (days)	Volumetric BOD load (g/m^3 day)	Percentage BOD removal
A2/1	0.8	306	76
A6	1.0	215	76
A4/1	1.9	129	80
A1/3	2.0	116	75
A1/2	4.0	72	68
A1/1	6.8	35	74

looked like this. The percentage BOD removals are much of a muchness, and really, for this strength wastewater, there's no point in having a retention time longer than 1 day.

18.

Anaerobic ponds

- very good removal of BOD & SS
- this has effect of reducing land area requirement for overall pond system, so anaerobic ponds should always be used (except at small works serving only a few thousand people)

Because anaerobic ponds have such good removals of BOD and suspended solids, incorporating them into a series of ponds has the effect of reducing the land area needed for the pond system; so we should always use them, especially in warm climates; and we would only not use them at small systems serving just a few thousand people.

19.

Operation and maintenance

1. fly breeding in scum layer may be a problem: use a suitable larvicide
2. desludge when ⅓ full of sludge – this occurs every n years:

$$n = \frac{\text{⅓ (Pond volume, m}^3\text{)}}{\text{Sludge accumulation rate, m}^3\text{/caput year} \times \text{(Population)}}$$

~0.04 m^3/cap.yr in tropics
~0.08 m^3/cap.yr in Europe

There are two special O&M requirements for anaerobic ponds.

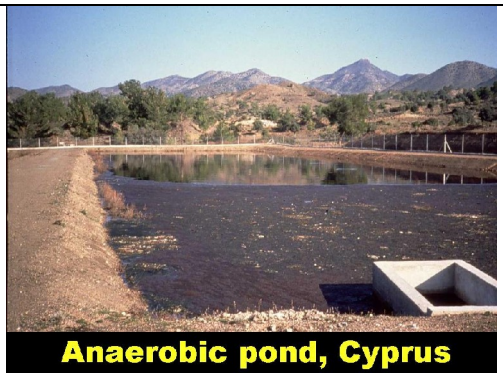
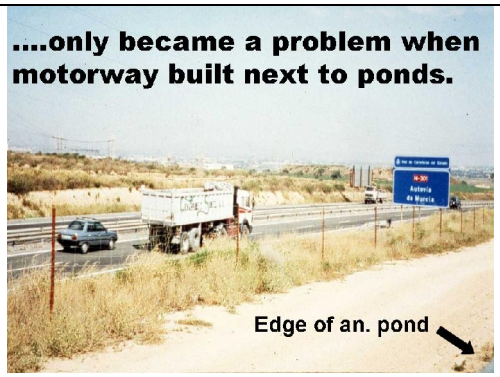
Firstly, you may need to spray the scum layer with a biodegradable larvicide if fly breeding becomes a nuisance.

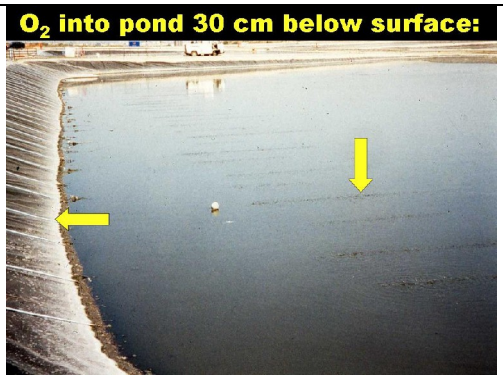
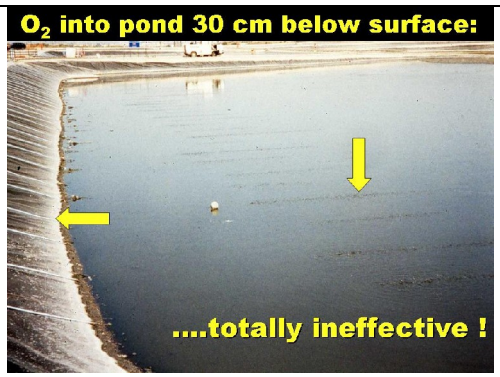
And secondly, the ponds need to be desludged regularly. They should never be allowed to be more than half full of sludge, and I prefer not to let them become more than a third full of sludge.

An anaerobic pond becomes a third full of sludge after *n* years, where *n* is equal to a third of the pond volume in m^3, divided by the sludge accumulation rate in m^3 per person per year and the population served. The value of the sludge accumulation rate is about 0.04 m^3/person year in the tropics and about 2–3 times this value in temperate climates.

20.

This slide shows the effluent from a slaughterhouse in central Cyprus; it's a strong wastewater with a BOD of around 1500–2000 mg/l.

21.		It's treated in two anaerobic ponds in parallel. These work very well, with BOD removals in excess of 80%, even in winter.
22.		This is Spain, a set of seven anaerobic ponds in parallel, in Murcia, just inland from the Costa Calida. There was a very strong smell of H_2S, but this wasn't a problem until …
23.		a motorway was built immediately adjacent to the ponds, and motorists started complaining about the smell.
24.		This silo structure was at the site. It contains liquid oxygen and was a so-called 'solution' to the odour problem.

25.		What they did was to introduce oxygen into the ponds via the plastic tubing you can see on the left of the slide; and you can also see the lines of oxygen bubbles across the pond. However, …
26.		this was a totally ineffective 'solution'.
27.	**Anaerobic ponds, Murcia** • Strong hydrogen sulphide odour • Source of sulphates? The local drinking water had a sulphate concentration of 600−1200 mg/l (far in excess of EU Drinking Water Quality Directive – max: 250 mg SO_4/l) So TREAT THE DRINKING WATER !! – and the odour problem will vanish !! • successfully done in the next province!	So what was the source of the sulphate in the wastewater? It transpired that the local drinking water had a sulphate concentration way in excess of the maximum of 250 mg SO_4/l permitted in the Drinking Water Directive; in fact it was around 600−1200 mg/l. So the correct solution was to treat the drinking water. This had been successfully done in the next Province when it had the same problem and the odour then disappeared.