Waste Stabilization Ponds: Past, Present and Future

Duncan Mara
School of Civil Engineering
Natural vs Conventional Wastewater Treatment

- Basically a choice between LAND and ELECTRICITY:
  - Money spent on land is an investment
  - Money spent on electricity is money gone for ever
WSP: The Past

• Early work in USA (Caldwell, 1946; ‘Ten States’ Standards)

• Pioneering research by Oswald (USA) and Marais (southern Africa)
High-rate algal ponds: low-cost protein for animal feeds — “sewage to beefsteak”
Algal–bacterial mutualism

**Role of Algae in Sewage Oxidation Ponds**

Harvey F. Ludwig and William J. Oswald

Sanitary Engineering Laboratory, University of California, Berkeley

Light

New cells

Algae

$\text{O}_2$

Bacteria

$\text{CO}_2$

Wastewater BOD

New cells
1961: ‘A rational theory for the design of sewage stabilization ponds in central and south Africa’
Transactions of the South African Institution of Civil Engineers 3, 205–227

Application of first-order kinetics in a completely mixed reactor to the design of facultative ponds:

\[ L_e = \frac{L_i}{1 + k_1 \theta} \]
1961:
‘A rational theory for the design of sewage stabilization ponds in central and south Africa’
*Transactions of the South African Institution of Civil Engineers* 3, 205–227

1966:

New Factors in the Design, Operation and Performance of Waste-stabilization Ponds

G. v. R. MARAIS

In the developing countries, the unit costs of waste-stabilization ponds are generally low. Moreover, in the tropics and subtropics, the environmental conditions are conducive to a high level of pond performance. In view of this, the theory, operation and performance of such ponds under these conditions have been studied.
“Anaerobic pretreatment is so advantageous that the first consideration in the design of a series of ponds should always include the possibility of anaerobic pretreatment.”
1974:
Faecal bacterial kinetics in waste stabilization ponds
*Journal of the Environmental Engineering Division*, ASCE, 100 (EE1), 119–139.

\[ K_{B(T)} = 2.6(1.19)^{T-20} \]

and so for the first time it became possible to design WSP for faecal bacterial removal.
Excellent agreement between actual FC numbers in pond effluents in northeast Brazil and numbers predicted by Marais’ equation (25°C)

WST 31 (12), 129–139 (1995)
The Present of WSP owes much to

Bill Oswald

Gerrit Marais
Our Present:
A world with too little wastewater treatment
Effective wastewater treatment − 2000

WSP: The Present

- ~2500 WSP systems in France
- ~3000 in Germany (inc. ~1500 in Bavaria)
- ~7500 in USA (⅓ of all WWTP are WSP)
- and in many other countries
WSP: The Present

- Major WSP research programmes at, for example:
  - University of California at Berkeley
  - Federal Universities of Paraíba and Minas Gerais, Brazil; Univalle, Colombia
  - Flinders University, Australia
  - AIT, Thailand; Massey University, NZ
  - Universities of Montpellier I & II, France
  - University of Leeds, UK
WSP: The Present

- IWA International WSP Conferences (Lisbon, 1987 – Belo Horizonte 2009)
- Several design guides, manuals and books
- But one major disappointment:

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BRITISH STANDARD

Actually a European standard

Wastewater treatment plants —
Part 5: Lagooning processes

BS EN 12255-5:1999
Incorporating Corrigendum No.1
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Table 1: Requirements for discharges from urban waste water treatment plants subject to Articles 4 and 5 of the Directive. The values for concentration or for the percentage of reduction shall apply.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Concentration</th>
<th>Minimum percentage of reduction ('')</th>
<th>Reference method of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochemical oxygen demand (BOD₅ at 20 °C) without nitrification ('')</td>
<td>25 mg/l O₂</td>
<td>70-90</td>
<td>Homogenized, unfiltered, undecanted sample. Determination of dissolved oxygen before and after five-day incubation at 20 °C ± 1 °C, in complete darkness. Addition of a nitrification inhibitor</td>
</tr>
<tr>
<td>Chemical oxygen demand (COD)</td>
<td>125 mg/l O₂</td>
<td>75</td>
<td>Homogenized, unfiltered, undecanted sample Potassium dichromate</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>35 mg/l ('')</td>
<td>90 ('')</td>
<td>— Filtering of a representative sample through a 0.45 μm filter membrane. Drying at 105 °C and weighing</td>
</tr>
<tr>
<td></td>
<td>35 under Article 4 (2) (more than 10 000 p.e.)</td>
<td>90 ('')</td>
<td>— Centrifuging of a representative sample (for at least five mins with mean acceleration of 2 800 to 3 200 g), drying at 105 °C and weighing</td>
</tr>
<tr>
<td></td>
<td>60 under Article 4 (2) (2 000-10 000 p.e.)</td>
<td>70 ('')</td>
<td></td>
</tr>
</tbody>
</table>

('') Reduction in relation to the load of the influent.
('') The parameter can be replaced by another parameter: total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD₅ and the substitute parameter.
(') This requirement is optional.

Analyses concerning discharges from lagooning shall be carried out on filtered samples; however, the concentration of total suspended solids in unfiltered water samples shall not exceed 150 mg/l.

So for WSP effluents:

≤25 mg filtered BOD/l &
≤150 mg SS/l
WSP: The Present

Improved understanding of:

- Faecal bacterial removal mechanisms (including removal of Vibrio cholerae)
- Nitrogen removal mechanisms and pathways
- Facultative pond performance in temperate climates

Ability to design WSP specifically for helminth egg removal
WSP: The Present

Several important developments:

- Greatly improved understanding of **WSP hydraulics**, enabling rational design of baffles (dramatic improvement in performance – so much so that now wrong not to baffle facultative ponds)
- **High-rate anaerobic ponds**
- **Rock filters** to treat **fac. pond effluents**
High-rate anaerobic pond
Cerrito, Valle del Cauca, Colombia
WSP effluents: algal SS

We shouldn’t think of algal SS as a problem!

**Conventional wastewater treatment:**
Biological treatment + secondary sedimentation

**Waste stabilization ponds:**
Facultative pond + rock filter
We shouldn’t think of algal SS as a problem!

**Conventional wastewater treatment:**

Biological treatment + secondary sedimentation

**Waste stabilization ponds:**

Facultative pond + rock filter

Biomass removal
WSP effluents: algal SS

We shouldn’t think of algal SS as a problem!

Conventional wastewater treatment:
   Biological treatment + secondary sedimentation

Waste stabilization ponds:
   Facultative pond + rock filter

“WSP system”
• Used in the US for over 30 years to ‘polish’ maturation pond effluents, but actually better to use them to polish facultative pond effluents

• Purpose: to remove algal SS and associated BOD
Planted filter (*Typha*)

Unaerated filter

Aerated filter
All receiving facultative pond effluent
Summer Results for effluent ammonia-N/l:

Aerated RF: <3 mg/l

Unaerated RF: ~7 mg/l

Planted bed: ~4 mg/l
BUT

Winter

Results for effluent ammonia-N/l:

Aerated RF: <3 mg/l

Unaerated RF: ~8 mg/l

Planted bed: ~7 mg/l
Aerated rock filter
Mean effluent quality 2006
HLR = 0.6 day$^{-1}$

- BOD: 9 mg/l
- SS: 7 mg/l
- Amm.N: 2.6 mg/l
- F. coliforms: <1000/100 ml
Our Future:

A water-short world
World population (billions)

Population in water-scarce & water-stressed countries (billions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>0.46</td>
</tr>
<tr>
<td>2025</td>
<td>2.8</td>
</tr>
<tr>
<td>2050</td>
<td>4</td>
</tr>
</tbody>
</table>
Our Future:

An urban world
Actually a **poor** urban world

Source: *World Urbanization Prospects: The 2007 Revision*
WSP: The Future

- Treated wastewater use in aquaculture and/or agriculture (preferably “and”)
- “Water for Cities, Treated Wastewater for Agriculture”
- WSP especially suitable for treatment prior to reuse
- Wastewater Storage & Treatment Reservoirs likely to be used much more
WSTR at Arad, Israel

Sequential batch-fed WSTR

Covered anaerobic pond
Biofuel production (CH₄)

WSTR in “rest” phase

WSTR in “use” phase
WHO 2006 Guidelines

A major change from the 1989 Guidelines

Now risk-based (QMRA)

Actually not so complicated!

- Less wastewater treatment needed for unrestricted irrigation
WHO 2006 Guidelines

A major change from the 1989 Guidelines
Now risk-based (QMRA)
Actually not so complicated!
➢ Less wastewater treatment needed for unrestricted irrigation

Already being updated to take into account developments since 2005
ASCARIS

- For $10^{-5}$ DALY loss pppy, the tolerable Ascaris infection risk is $\sim10^{-3}$ pppy
- In hyperendemic areas this is achieved by a 4-log unit Ascaris reduction (from 1000 epl to 0.1 epl)
- BUT only 2 log units through treatment (1-d anaerobic pond + 5-d facultative pond) as:
  - 2 log reduction by peeling

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Median Ascaris infection risks for children under 15 from the consumption of wastewater-irrigated raw carrots estimated by 10,000-trial Monte Carlo simulations*

<table>
<thead>
<tr>
<th>Number of Ascaris eggs per litre of wastewater</th>
<th>Median Ascaris infection risk pppy</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>100–1000</td>
<td>0.86</td>
<td>Raw wastewaters in hyperendemic areas.</td>
</tr>
<tr>
<td>10–100</td>
<td>0.24</td>
<td>Raw wastewaters in endemic areas.</td>
</tr>
<tr>
<td>1–10</td>
<td>$2.9 \times 10^{-2}$</td>
<td>Treated wastewaters.</td>
</tr>
<tr>
<td>1</td>
<td>$5.5 \times 10^{-3}$</td>
<td>Wastewater quality required to comply with the 1989 and 2006 WHO Guidelines.</td>
</tr>
<tr>
<td>0.1–1</td>
<td>$3.0 \times 10^{-3}$</td>
<td>Highly treated wastewaters.</td>
</tr>
<tr>
<td>0.1</td>
<td>$5.5 \times 10^{-4}$</td>
<td>Wastewater quality recommended by Blumenthal et al. (2000).</td>
</tr>
<tr>
<td>0.01–0.1</td>
<td>$3.0 \times 10^{-4}$</td>
<td>Treated wastewaters in non-endemic areas.</td>
</tr>
</tbody>
</table>

*Assumptions: 30–50 g raw carrots consumed per child per week (Navarro et al. 2009); 3–5 ml wastewater remaining on 100 g carrots after irrigation (Mara et al. 2007); $N_{50} = 859 \pm 25\%$ and $\alpha = 0.104 \pm 25\%$; no Ascaris die-off between final irrigation and consumption.
Solar-powered aeration and disinfection, anaerobic co-digestion, biological CO₂ scrubbing and biofuel production: the energy and carbon management opportunities of waste stabilisation ponds

A. N. Shilton, D. D. Mara, R. Craggs and N. Powell

Presented at IWA Congress in Vienna, September 2008
WESTERN TREATMENT PLANT, MELBOURNE
Covered part of anaerobic section of first pond

**BIOGAS COLLECTION**

Electricity generation:
6000 kW for 8-16 h/d, 365 d/year
WESTERN TREATMENT PLANT, MELBOURNE
Covered part of anaerobic section of first pond
BIOGAS COLLECTION
Electricity generation:
6000 kW for 8-16 h/d, 365 d/year

GREEN ENERGY

CARBON CREDITS
Clean Development Mechanism in developing countries
WSP: The Future?

ALGAL BIOFUEL

CALIFORNIA: algae to jet fuel
First flight of algae-fuelled jet

A US airline has completed the first test flight of a plane partly powered by biofuel derived from algae.

The 90-minute flight by a Continental Boeing 737-800 went better than expected, a spokesperson said.

One of its engines was powered by a 50-50 blend of biofuel and normal aircraft fuel.

Wednesday's test is the latest in a series of demonstration flights by the aviation industry, which hopes to be using biofuels within five years.

The flight was the first by a US carrier to use an alternative fuel source, and the first in the world to use a twin-engine commercial aircraft (rather than a four-engine plane) to test a biofuel blend.
Algal Biofuels

Biofuels made from microalgae hold the potential to solve many of the sustainability challenges facing other biofuels today.

Algal biofuels are generating considerable interest around the world. They may represent a sustainable pathway for helping to meet the U.S. biofuel production targets set by the Energy Independence and Security Act of 2007.

Renewed Interest and Funding
Higher oil prices and increased interest in energy security have stimulated new public and private investment in algal biofuels research. The Biomass Program is reviving its Aquatic Species Program at the National

Benefits of Algal Biofuels

Impressive Productivity:
Microalgae, as distinct from seaweed or macroalgae, can potentially produce 100 times more oil per acre than soybeans—or any other terrestrial oil-producing crop.
RENEWABLE FUELS

Cultivating Algae At Wastewater Treatment Plants

Photo bioreactors contain algae – fed with wastewater and carbon dioxide emissions – that will be harvested to produce biodiesel and animal feed.
“The cultivation of microalgae for biofuels in general and oil production in particular is not yet a commercial reality and, outside some niche, but significant, applications in wastewater treatment, still requires relatively long-term R&D...”
WSP
(actually HRAP):
The Future

Clearly much R&D on algal biofuel production!
But we must NOT lose sight of the ‘basics’

%}

INCREASE!

INCREASE!
Our Future:

We will need a world with more WSP and WSTR.
Thank you!

Obrigado!