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Waste stabilization ponds: Past, present and future

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ABSTRACT

The 'past' of waste stabilization ponds (WSP) is due to early experience and design codes in the USA and also to two pioneering researchers, Oswald and Marais. The 'present' of WSP dates from the mid-to-late 1970s and is characterized by large numbers of full-scale systems in France, Germany and the USA. Research expanded greatly in several universities around the world, and much more is now known about pathogen and nitrogen removal in WSP, design procedures, WSP hydraulics and the benefits of baffling, and facultative pond effluent polishing in aerated and unaerated rock filters. Several design manuals, books and reference works have been published. The 'future' of WSP should see many more systems, including wastewater storage and treatment reservoirs, installed in both industrialized and developing countries, with pond/reservoir effluent reuse in aquaculture and agriculture, so making a large contribution to global food production.

Keywords: Waste stabilization ponds; History; Prospectives; Design; Research

1. Introduction

All of us at this conference know what waste stabilization ponds (WSP) are, but none of us knows everything about them as new research and new operational experiences are always extending our knowledge. We know that natural wastewater treatment systems, of which WSP are the best example, are more sustainable than electromechanical treatment systems, although we cannot always use WSP (for example, large cities, at least those in industrialized countries, are generally unserviceable by them), but we should always use them whenever we can. This means we have to 'sell' WSP more effectively than those who market electromechanical systems [1] or indeed those who passionately promote constructed wetlands [2–4]. Many, perhaps most, wastewater treatment engineers seem to have an in-built prejudice against WSP, but this is only due to ignorance, and ignorance can be 'cured' by knowledge transfer and experience. However, we still have to work very hard to remove these prejudices.

One 'selling' point that we need to make, and make continually, is that the choice between natural wastewater treatment systems and electromechanical systems is basically a choice between spending your money on land and spending it on electricity. Money spent on land is an investment (a good example is given by Oswald [5]), whereas money spent on electricity is money gone forever!

2. WSP: the past

The 'past' of WSP belongs mainly to early experience and design codes (such as the 'Ten States Standards') in the United States [6"9] and to two engineering professors in particular: Oswald in the USA and Marais in southern Africa (both of whom died in 2005). The work of these two WSP research pioneers is the basic foundation of the Present of WSP [5,10–16].

3. WSP: the present

The 'present' of WSP dates from the mid-to-late 1970s when France and Germany started to use WSP systems: by 1987 France had ~2000 WSP systems [17] and Germany ~1100 [18]. Currently there are >2500 WSP systems

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in France and ~3000 in Germany, including ~1500 in Bavaria alone, and in the USA ~7000 [19]. WSP are also used, but not in such large numbers, in many other industrialized and developing countries.

The present of WSP is characterized by much more research: large research WSP programmes continued during the present (e.g., at the University of California at Berkeley) and some were started during the present (e.g., at the Federal Universities of Minas Gerais and Paraíba in Brazil, Instituto Cinara at the University of Valle in Colombia, the Universities of Montpellier I and II in France, the Asian Institute of Technology in Thailand, Massey University in New Zealand, and the University of Leeds in England). Research results have been presented at the international WSP conferences organized by the WSP specialist group of the International Water Association and its predecessor bodies — the first of these was held in Lisbon in 1987 and the seventh in Bangkok in 2006. World Bank guidance on WSP in developing countries was issued in 1983 (and this still contains the best methodology for choosing between different wastewater treatment processes) [20]. Several WSP design manuals have been produced [19,21–25], as have reference works [26–30], and France produced an important review of its WSP experience [31]. The only real disappointment is the European Standard for "the performance requirements for the installation of lagooning processes" [32], which is not nearly as useful as the guidance document produced by the Environment Protection Agency of South Australia [33].

The major research highlights of the present of WSP are that we now know much more about (a) faecal bacterial removal mechanisms in WSP [34–36]; (b) WSP design for helminth egg removal [37]; (c) nitrogen removal pathways and mechanisms in WSP [38"40]; and (d) facultative pond performance in temperate climates [41]. Two other developments stand out: (a) a greatly improved understanding of WSP hydraulics and the resultant ability to design baffles rationally [25,42] — given that baffling has been shown to increase performance so dramatically, I would now consider it wrong not to baffle facultative and maturation ponds; and (b) the use of rock filters to 'polish' facultative pond effluents [43–46] — this use of rock filters is a significant advance as it means that maturation ponds are no longer always required (in contrast, rock filters are used in the USA to polish maturation pond effluents [47–50]).

Abis [41] found that a primary facultative pond loaded at ~80 kg BOD ha^{-1} d^{-1} produces an effluent which complies with the requirements for WSP effluents in the Urban Waste Water Treatment Directive (UWWTD), namely ≤ 25 mg filtered BOD l^{-1} and ≤ 150 mg suspended solids (SS) l^{-1} [51]. These requirements are quite lax and so may not satisfy all environmental regulators in the European Union, especially as they implement the Water Framework Directive [52]. It is here that aerated rock filters [43–46] become attractive: a small expenditure on energy not only greatly reduces land area requirements but also leads to much better performance in terms of BOD, SS, ammonia-N and faecal coliform removals — effluent concentrations of <10 mg BOD and SS l^{-1}, <3 mg ammonia-N l^{-1}, and <1000 faecal coliforms per 100 ml have been obtained at a hydraulic loading rate of 0.6 m^3 of facultative pond effluent m^{-3} of rock filter volume d^{-1} [Johnson, unpublished data].

4. WSP: the future

What of the 'future' of WSP? I see their future as very good. For small communities I see very simple WSP systems [53] as being necessary and implemented on a much larger scale than at present as engineers, prompted perhaps by public opinion that "natural" is better than "electromechanical", learn that WSP are not only low-cost and low-maintenance but also extremely high-performance. My view of a 'simple' WSP system suitable for small communities up to ~500 p.e. is that it should comprise a two-compartment septic tank [54] followed by a baffled secondary facultative pond and a rock filter, with the rock filter being aerated if ammonia-nitrogen removal is required [53]. For larger communities, up to ~2000 (the limit of 'small' in the UWWTD), an Imhoff tank can be used in place of the septic tank. (Septic and Imhoff tanks are recommended not only to protect the algae in the facultative pond, especially in winter, but also to facilitate desludging — no one worries about desludging these reactors, but inexperienced engineers often think that pond desludging every 10 years or so is just 'too big a task'.)

I do not share Oswald's vision of high-rate algal ponds (HRAP) being widely used in this century [55,56], simply because I do not believe that there will be a high demand for algal protein for use as animal feed ("sewage to beefsteak" [10]) — well, not in the next 25 years or so. In any case HRAP, as a treatment/algal-protein-production facility, are and will remain totally unsuitable for small communities.

However, I do believe that, as water scarcity increases (and increase it will — Fig. 1), the use of wastewater storage and treatment reservoirs (WSTR) [58,59] or hybrid WSTR–WSP systems [60] should be used on a much larger scale than at present, even for small communities, as wastewater use in agriculture [61] or small-scale horticulture becomes more commonplace in all parts of the world. Wastewater-fed fish culture [62–64], ideally prior to crop irrigation [65], will also become more common.

Reuse will become so important to feed the ~2.5 billion 'new' people arriving in the next 25–30 years that even conservative engineers will realise that 'wastewater is too valuable to waste' and that wastewater treat-

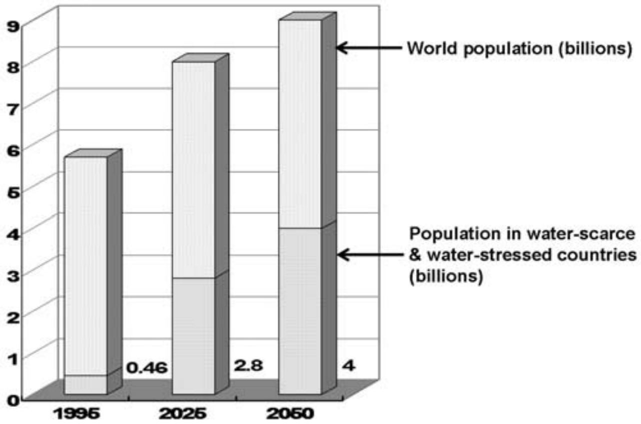

Fig. 1. World population and population in water-scarce and water-stressed countries, 1995–2050 [57].

ment in WSP and WSTR is an extremely reliable way to ensure the safety of the food so produced.

References

[1] D.D. Mara, Waste stabilization ponds: time for aggressive marketing, M.R. Peña, I. Restrepo, D.D. Mara and H. Gijzen, eds., Aqua 2003: Multiple Uses of Water for Life and Sustainable Development, IWA Publishing, London, 2005, pp. 129–130.

[2] D.D. Mara, To plant or not to plant? Questions on the role of plants in constructed wetlands, Paper presented at the joint session of the Ninth IWA International Conference on Constructed Wetlands and the Sixth IWA International Conference on Waste Stabilization Ponds, Avignon, France, 2004.

[3] D.D. Mara, Constructed wetlands are not a viable alternative or addition to waste stabilization ponds, Paper presented at the 7th IWA International Conference on Waste Stabilization Ponds, Bangkok, Thailand, 2006.

[4] D.D. Mara, Constructed wetlands and waste stabilization ponds for small rural communities in the United Kingdom: a comparison of land area requirements, performance and costs, Environ. Technol., 27(4) (2006) 573–757.

[5] W.J. Oswald, Experiences with new pond designs in California, E.F. Gloyna, J.F. Malina and E.M. Davis, eds., Ponds as a Wastewater Treatment Alternative, University of Texas Press, Austin TX, 1976, pp. 257–272.

[6] D.H. Caldwell, Sewage oxidation ponds: performance, operation and design, Sewage Works J., 18(3) (1946) 433–458.

[7] E.D. Dildine and J.R Franzmathes, Current design criteria for oxidation ponds, R.E. McKinney, ed., Proc. Second International Symposium for Waste Treatment Lagoons, University of Kansas, Lawrence KS, 1970, pp. 194–200.

[8] Waste Stabilization Lagoons: A Review of Research and Experience in Design, Construction, Operation and Maintenance. US Department of Health, Education and Welfare, Washington DC, 1961.

[9] R.E. McKinney, Proc. Second International Symposium for Waste Treatment Lagoons, University of Kansas, Lawrence KS, 1970.

[10] H.F. Ludwig and W.J. Oswald, Role of algae in sewage oxidation ponds, The Scientific Monthly, 74(1) (1952) 3–6.

[11] H.B. Gotaas, W.J. Oswald and H.F. Ludwig, Photosynthetic reclamation of organic wastes, The Scientific Monthly, 79(6) (1954) 368–378.

[12] W.J. Oswald, Waste Pond Fundamentals, The World Bank, Washington DC, 1975.

[13] G.v.R. Marais and V.A. Shaw, A rational theory for the design of sewage stabilization ponds in central and south Africa, Trans. South Afr. Inst. Civil Eng., 3 (1961) 205–227.

[14] G.v.R. Marais, New factors in the design, operation and performance of waste stabilization ponds, Bull. WHO, 34(5) (1966) 737–763.

[15] G.v.R. Marais, Dynamic behaviour of oxidation ponds, R.E. McKinney, ed., Proc. Second International Symposium for Waste Treatment Lagoons, University of Kansas, Lawrence KS, 1970, pp. 15–46.

[16] G.v.R. Marais, Faecal bacterial kinetics in waste stabilization ponds, J. Environ. Eng. Div., ASCE, 100 (EE1) (1974) 119–139.

[17] P. Boutin, A. Vachon and Y. Racault, Waste stabilization ponds in France: an overall review, Water Sci. Technol., 19(12) (1987) 25–31.

[18] K. Bucksteeg, German experiences with sewage treatment ponds, Water Sci. Technol., 19(12) (1987) 17–23.

[19] Design Manual: Municipal Wastewater Stabilization Ponds, US Environmental Protection Agency, Cincinnati OH, 1983.

[20] J.P. Arthur, Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries, The World Bank, Washington DC, 1983.

[21] A.R. Townsend and H. Knoll, Cold Climate Sewage Lagoons, Environment Canada, Ottawa, 1987.

[22] D.D. Mara and H.W. Pearson, Waste Stabilization Ponds: Design Manual for Mediterranean Europe, World Health Organization Regional Office for Europe, Copenhagen, 1987.

[23] D.D. Mara and H.W. Pearson, Design Manual for Waste Stabilization Ponds in Mediterranean Countries, Lagoon Technology International, Leeds, 1998.

[24] D.D. Mara, Design Manual for Waste Stabilization Ponds in India, Lagoon Technology International, Leeds, 1997.

[25] A.N. Shilton and J. Harrison, Guidelines for the Hydraulic Design of Waste Stabilization Ponds, Massey University, Palmerston North, New Zealand, 2003.

[26] C.O. de Andrade Neto, Sistemas Simples para Tratamento de Esgotos Sanitários: Experiência Brasileira, Associação Brasileira de Engenharia Sanitária e Ambiental, Rio de Janeiro, 1997.

[27] D.D. Mara, Domestic Wastewater Treatment in Developing Countries, Earthscan Publications, London, 2004.

[28] M.R. Peña Varón and D.D. Mara, Waste Stabilization Ponds — Thematic Overview Paper, IRC International Water and Sanitation Centre, Delft, 2004.

[29] M. von Sperling and C.A. de Lemos Chernicharo, Biological Wastewater Treatment in Warm Climate Regions, IWA Publishing, London, 2005.

[30] D.D. Mara, Good Practice in Water and Environmental Management: Natural Wastewater Treatment, Chartered Institute of Water and Environmental Management, London, 2007.

[31] Cemagref and Agences de l'Eau, Le Lagunage Naturel: Les Leçons Tirées de 15 Ans de Pratique en France, Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forets, Lyon, 1997.

[32] Wastewater Treatment Plants — Part 5: Lagooning Processes (European Standard No. EN 12255-5:1999), Comité Européen de Normalisation, Brussels, 1999.

[33] Wastewater and Evaporation Lagoon Construction, Environment Protection Agency, Adelaide, South Australia, 2004.

[34] T.P. Curtis, D.D. Mara and S.A. Silva, Influence of pH, oxygen and humic substances on ability of sunlight to damage faecal coliforms in waste stabilization pond water, Appl. Environ. Microbiol., 58(4) (1992) 1335–1343.

[35] J.I. Oragui, H. Arridge, D.D. Mara, H.W. Pearson and S.A. Silva, *Vibrio cholerae* O1 (El Tor) removal in waste stabilization ponds in northeast Brazil, Water Res., 27(4) (1993) 727–728.

[36] M. von Sperling, Modelling of coliform removal in 186 facultative and maturation ponds around the world, Water Res., 39 (2005) 5261–5273.

[37] R.M. Ayres, G.P. Alabaster, D.D. Mara and D.L. Lee, A design equation for human intestinal nematode egg removal in waste stabilization ponds, Water Res., 26(6) (1992) 863–865.
[38] M.A. Camargo Valero and D.D. Mara, Nitrogen removal in maturation ponds: tracer experiments with ^{15}N-labelled ammonia, Water Sci. Technol., 55(11) (2007) 81–85.
[39] M.A. Camargo Valero and D.D. Mara, Nitrogen removal via ammonia volatilization in maturation ponds, Water Sci. Technol., 55(11) (2007) 87–92.
[40] M.A. Camargo Valero and D.D. Mara, Nitrogen transformation and removal in maturation ponds: tracer experiments with ^{15}N stable isotopes in the UK in summer, Paper presented at SmallWat2007, Seville, 2007.
[41] K.L. Abis, The performance of facultative waste stabilisation ponds in the United Kingdom, PhD thesis, University of Leeds, Leeds, 2002.
[42] C.G. Banda, Computational fluid dynamics modelling of baffled waste stabilization ponds. PhD thesis, University of Leeds, Leeds, 2007.
[43] M.L. Johnson and D.D. Mara, Ammonia removal from facultative pond effluents in a constructed wetland and an aerated rock filter: performance comparison in winter and summer, Water Environ. Res., 79(5) (2007) 567–570.
[44] M.L. Johnson, M.A. Camargo Valero and D.D. Mara, Maturation ponds, rock filters and reedbeds in the UK: statistical analysis of winter performance, Water Sci. Technol., 55(11) (2007) 135–142.
[45] D.D. Mara and M.L. Johnson, Aerated rock filters for enhanced ammonia and fecal coliform removal from facultative pond effluents, J. Environ. Eng., ASCE, 132 (4) (2006) 574–577.
[46] D.D. Mara and M.L. Johnson, Waste stabilization ponds and rock filters: solutions for small communities, Water Sci. Technol., 55(7) (2007) 103–107.
[47] G.R. Swanson and K.J. Williamson, Upgrading lagoon effluents with rock filters, J. Environ. Eng. Div., ASCE, 106 (EE6) (1980) 1111–1129.
[48] E.J. Middlebrooks, Upgrading pond effluents: an overview, Water Sci. Technol., 31(12) (1995) 353–368.
[49] E.J. Middlebrooks, Review of rock filters for the upgrade of lagoon effluents, J. Water Pollut. Control Fed., 60(9) (1988) 1657–1662.
[50] Rock Media Polishing Filter for Lagoons, US Environmental Protection Agency, Washington DC, 2002.
[51] Directive 91/271/EEC of Council of the European Communities of 21 May 1991 concerning urban waste water treatment, Official J. European Communities, L135 (1991) 40–52.
[52] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, Official J. European Communities, L327 (2000) 1–72.
[53] D.D. Mara, Septic tanks, baffled facultative ponds and aerated rock filters: a high-efficiency low-cost wastewater treatment system for small communities up to ~500 p.e., E-Water (www.ewaonline.de/journal/online.htm), paper #19/06, 2006.
[54] Septic Tank Systems for Large Flow Applications, US Environmental Protection Agency, Washington DC, 2000.
[55] W.J. Oswald, Introduction to advanced integrated wastewater ponding systems, Water Sci. Technol., 24(5) (1991) 1–7.
[56] W.J. Oswald, Ponds in the twenty-first century, Water Sci. Technol., 31(12) (1995) 1–7.
[57] D. Hinrichsen, B. Robey and U.D. Upadhyay, Solutions for a Water-short World, Johns Hopkins University Press, Baltimore MD, 1998.
[58] M. Juanicó and I. Dor, Hypertrophic Reservoirs for Wastewater Storage and Reuse: Ecology, Performance, and Engineering Design, Springer Verlag, Heidelberg, 1999.
[59] D.D. Mara and H.W. Pearson, Sequential batch-fed effluent storage reservoirs: a new concept of wastewater treatment prior to unrestricted crop irrigation, Water Sci. Technol., 26(7–8) (1992) 1459–1464.
[60] D.D. Mara and H.W. Pearson, A hybrid waste stabilization pond and wastewater storage and treatment reservoir system for wastewater reuse for both restricted and unrestricted irrigation, Water Res., 33(2) (1999) 591–594.
[61] Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Vol. 2: Wastewater Use in Agriculture, World Health Organization, Geneva, 2006.
[62] P. Edwards, Reuse of Human Wastes in Aquaculture, The World Bank, Washington DC, 1992.
[63] D.D. Mara, P. Edwards, D. Clark and S.M. Mills, A rational approach to the design of wastewater-fed fishponds, Water Res., 27(12) (1993) 1797–1799.
[64] Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Vol. 3: Wastewater and Excreta Use in Aquaculture, World Health Organization, Geneva, 2006.
[65] Integrated Agriculture-Aquaculture: A Primer (Fisheries Technical Paper No. 407), Food and Agriculture Organization, Rome, 2001.