

**ADVANCED PRIMARY TREATMENT OF DOMESTIC WASTEWATER IN
TROPICAL COUNTRIES: DEVELOPMENT OF HIGH-RATE ANAEROBIC
PONDS**

By

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ABSTRACT

Domestic wastewater treatment is far from satisfactory in most Latin American countries. Coverage of sanitation services (i.e. excreta disposal, wastewater collection and conveyance) is low particularly in small municipalities and rural settlements of the Andean Region. WSP and anaerobic reactors have been widely used in various countries of Latin America during the last decades. However, there are some aspects of these technologies that deserve further investigation in order to develop more efficient yet simple and affordable process configurations that can effectively contribute to the reduction of water pollution and public health improvements in small municipalities and rural areas of most Latin American countries.

This work therefore focuses on the study of the hydrodynamics and process performance of two well-established primary anaerobic treatment systems, the anaerobic pond (AP) and the upflow anaerobic sludge blanket (UASB) reactor. The hydrodynamics and biological process performance of APs may be further improved by applying fundamental principles from reactor engineering and anaerobic treatment theory so that current reaction rates in these units are enhanced. This will clearly improve the applicability of this technology and waste stabilisation ponds (WSP) at large provided that simplicity of operation and maintenance (O&M) is kept. An improved or high-rate AP configuration may be obtained by combining the best features of the two technologies mentioned above (AP and UASB) based on their evaluation under the same conditions.

The methodology comprised three main steps: first, studies of the hydrodynamic behaviour of two full-scale AP and a full-scale UASB reactor were carried out to find out their mixing patterns and related process performance. Second, computational fluid dynamics (CFD) simulations of one of the full-scale AP were done so as to study the effects of sludge accumulation, baffling arrangements, inlet-outlet positioning and pond geometry on the overall hydrodynamic efficiency of the AP. Third, results from the full-scale studies were used to run hydrodynamic and process performance evaluations under steady state conditions on various modified pilot-scale AP configurations.

The results showed that full-scale AP had large flow deviations that produced low removal efficiencies related mainly to sludge accumulation, inadequate inlet-outlet positioning and poor geometric design. Meanwhile, the UASB showed a hydrodynamic behaviour very close to the CSTR model with two mixed compartments in series provided that it is properly loaded. Short-circuiting, dead zones and bypassing flows were observed during both underloading and overloading conditions. Experimental hydraulic retention time (HRT) values in the full-scale AP varied from 30 to 50% of the theoretical HRT. Experimental HRT values in the UASB varied from 60 to 100% of the theoretical HRT and this showed the superior hydrodynamic performance of this reactor compared to the AP. The CFD simulations of the full-scale AP showed, however, that two baffles located at $L/3$ and $2L/3$ along with diagonally opposite inlet-outlet devices and a rectangular geometry ($L: B = 2:1$), increase the experimental HRT up to 84% of the theoretical HRT.

On the other hand, the modified pilot-scale AP configurations [vertically baffled anaerobic pond (VBAP), plastic nets fitted anaerobic pond (PNFAP), horizontally baffled anaerobic pond (HBAP) and mixing pit fitted anaerobic pond (MPAP)] yielded an improved hydrodynamic behaviour in comparison with the conventional AP. The experimental HRT values varied from 70 to 100% of the corresponding theoretical HRT figures. This finding together with the closeness to the complete mixing pattern observed in all the pilot-scale APs confirmed one of the main characteristics of high-rate anaerobic reactors. The best configuration in terms of hydrodynamics was the MPAP, followed by the baffled configurations (VBAP and HBAP) and then the PNFAP. The process performance evaluation showed that the highest COD total removal efficiencies occurred in the MPAP (77-79%), followed by the HBAP (65-51%) and then the AP (67-49%). Improved hydrodynamics, enhanced contact pattern and better biomass retention explain the increasing COD filtered removal efficiencies found in the MPAP (50-78%). The HBAP and the AP removal efficiencies for COD filtered were (41-44%) and (44-53%) respectively. The removal of filtered COD is achieved mainly by direct biological action, which depends on a good external mass transfer process to and from the cells (biomass). The removals of faecal coliforms and *E. coli* were low in all the reactors as expected in anaerobic treatment systems. Removals of helminth eggs were higher in the MPAP configuration (51-67%) compared to the other modified AP configurations.

The whole set of results proved that it is possible to develop a high-rate AP by enhancing its hydrodynamics and related transport phenomena. The high organic matter removal efficiencies achieved at shorter HRT values (18-12 h) together with the enhanced biomass retention and the possibility of biogas recovery, confirmed the advanced primary treatment features of these modified AP configurations.

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ABBREVIATIONS

ABR	Anaerobic baffled reactor
AMB	Acetoclastic methanogenic bacteria
ANOVA	Analysis of variance
AP	Anaerobic pond
ASRB	Acetoclastic sulphate reducing bacteria
BMP	Biochemical methane potential
BOD	Biochemical oxygen demand
CEPIS	Pan-American centre of sanitary and environmental engineering
CFD	Computational fluids dynamics
COD	Chemical oxygen demand
CSTR	Completely stirred tank reactor
DFID	UK-Department for international development
GLS	Gas-Liquid-Solid separation device
HBAP	Horizontally baffled anaerobic pond
HMB	Hydrogenotrophic methanogenic bacteria
HSRB	Hydrogenotrophic sulphate reducing bacteria
HRT	Hydraulic retention time
MB	Methanogenic bacteria
MPAP	Mixing pit fitted anaerobic pond
ORP	Redox potential
PAHO	Pan-American health organization
PNFAP	Plastic nets fitted anaerobic pond
RTD	Retention time distribution curves
SMA	Specific methanogenic activity
SPSS	Statistical package for the social sciences
SRB	Sulphate reducing bacteria
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket reactor
UN	United Nations
UNEP	United Nations environmental programme
VBAP	Vertically baffled anaerobic pond
VFA	Volatile fatty acids
VSS	Volatile suspended solids
WHO	World health organization
WSP	Waste stabilization ponds
WWTP	Wastewater treatment plant