COMPARISON OF AEROBIC AND ANAEROBIC TECHNOLOGIES FOR DOMESTIC WASTEWATER TREATMENT BASED ON CASE STUDIES IN LATIN AMERICA

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ABSTRACT

Different from Europe, where continuous flow activated sludge plants are the first choice for domestic wastewater treatment, specific Latin American conditions promote alternative technical solutions. In many locations wastewater temperatures are relatively high, land is available and areas pestered with energy shortages abound. Moreover, there is little specialised mechanical equipment for wastewater treatment produced locally. Hence a drive towards technology with simple, low-cost and low-energy operation can be observed. This leads towards the application of UASB, waste stabilization ponds and trickling filters, whereas the number of activated sludge systems is restricted. This presentation intends to present general differences between these systems, taking reference to a series of different case studies in terms of site inherent conditions, performance and costs.

KEYWORDS

Wastewater treatment, low cost technology, UASB, waste stabilization pond, trickling filter, activated sludge, Biocos

GENERAL COMPARISON OF SELECTED WASTEWATER TREATMENT OPTIONS

	PST	**UASB**	**WSP**			**TF**	**AS**
environmental conditions	anaerobic	anaerobic	anaerobic	facultative	maturation	aerobic	aerobic
suited for raw sewage	++	+	++	++	-	+	++
suited for settled sewage	-	++	++	++	-	++	++
suited for wastewater temperatures	> 5°C	> 20°C	> 5°C	> 5°C	> 5°C	> 5°C	> 5°C
BOD removal efficiency	30-40%	> 70 %	> 50 %	> 70 %	> 50%	80-90%	> 90 %
nutrient (N, P) removal efficiency	-	-	-	-	-	+ (++)	+ (++)
coliform removal	25-75%	90%	90%	90-99%	> 99%	90-95%	90-98%
helminth egg removal	90%	90%	99%	99%	99%	90-99%	90-99%
typical HRT	1-2 h	ca. 6 h	> 1 d	> 4 d	> 3 d	ca. 6 h	ca. 15 h
odour nuisance	+	++	+	+	++	++	++
energy demand & gas production	++	++	++	++	++	+ (++)	-
land requirement	++	++	+	-	-	+	+
requiring skilled operators	++	+/-	++	++	++	+	-
investment cost	++	++	++	+	+	+	-

Table 1: Typical features of treatment technologies for domestic wastewater
(evaluation according to: ++ … excellent, + … positive, - … negative)
(Metcalf & Eddy 1996, Mara and Pearson 1998, Haandel and Lettinga G. 1994, Sperling et al. 2002)

The main features of the selected treatment options can be summarized as follows:

- Primary Sedimentation Tanks (PST) are relatively efficient in relation to investment cost. But they are never suited to comply with typical WWTP treatment standards, neither in Europe nor in Latin America.
- UASB is very efficient, its volume is small, but it typically requires post-treatment. As long as operation is running smoothly, it is not particularly skill demanding for the operators, but during start-up and in case of operational problems a certain level of process knowledge is indispensable.
- Waste stabilization ponds (WSP) are cheap, efficient in BOD removal – in particular if constructed in series -, simple to operate, do not require electrical energy, are most efficient in removing pathogens, but they require plenty of land. Additionally, depending on sulphate concentration in the crude wastewater and frequency of overloading they might pose an odour problem (Mara and Pearson 1998).
- Trickling filters (TF) are efficient for BOD removal, easy to operate and show little land requirement. And not least, in case of favourable topography they can be operated completely without electric energy. In flat areas, where electric energy is needed for pumping of the wastewater on to the top of the TF, it requires still just about 10 % of the energy need of an activated sludge plant (Hanisch 1990).
- Activated sludge systems (AS) are definitely the best choice for very efficient BOD and nutrient removal. But they are more expensive.

From an overall point of view it seems reasonable for Europe to work with AS systems, since requirements for BOD & nutrient removal is high, whereas wastewater temperatures are low, especially in winter time. On the other hand, Latin America with its not that stringent environmental regulations but a strong need for BOD & pathogens removal can definitely make good use of WSP, as it has frequently done in the past. Nowadays, with the development of new anaerobic technologies (UASB) emphasis should additionally shift this way. The challenge of the future will thus be to balance pros and cons of WSP against UASB as prime treatment plus the need to optimise post-treatment with aerobic systems, e.g. by means of ponds (Frasinetti and van Haandel, 1996), by trickling filters or by AS-SBR (de Sousa and Foresti, 1996), etc.

UASB APPLICATIONS

Upflow anaerobic sludge blanket (UASB) applications are relatively well known (and constructed) for domestic wastewater treatment in Colombia. But they are not widely spread in other parts of Latin America yet. If, they are used, then it is typically in industries, e.g. breweries or coffee processing, etc. One such example is an UASB reactor in El Salvador, which was constructed in 1999 by Cafeco S.A. de C.V. at the Beneficio Atapasco, Quezaltepeque. The design was done by one of the authors, when working for Beller Consult, Germany.

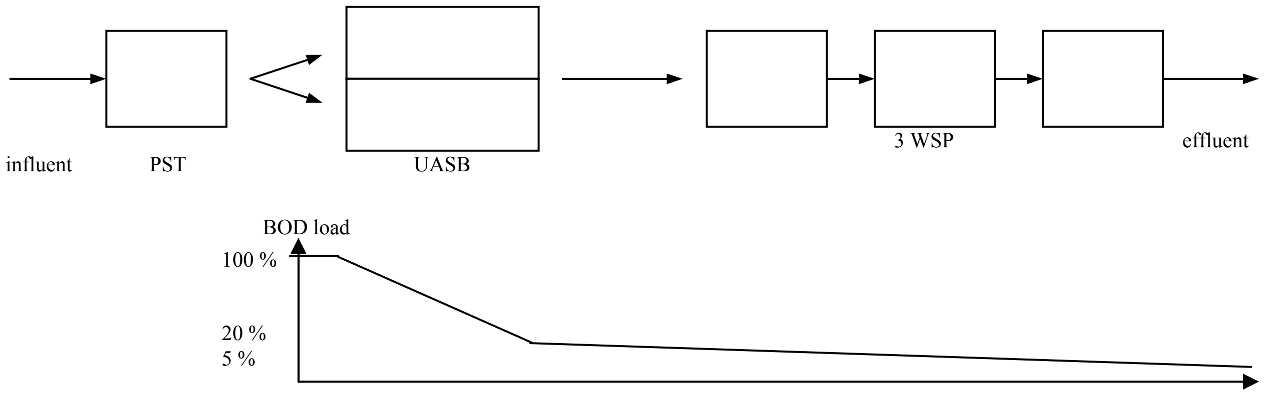

Figure 1: Schematic layout and course of BOD removal along the flowpath of the UASB plant for Cafeco S.A. de C.V., El Salvador.

Main design features of the plant are: maximum flow = 60 m3/h, BOD = 8,000 mg/l, SS = 4,000 mg/l, volume UASB = 750 m3, total volume of 3 WSP = 18,000 m3, overall BOD efficiency = 95%. The plant was started-up in 1999 and has been working satisfactorily ever since. About 80 % of the organic load of the settled wastewater is eliminated in the UASB and additional 15 % in the pond system resuming to a total biological treatment efficiency of 95 %. A special feature of the plant is that the coffee processing period in El Salvador usually lasts only about 4 months, the rest of the year the plant is lying idle. Nevertheless after the initial start-up in 1999, which took several months, a restart at the beginning of each coffee season is just a matter of a few days. And most remarkable , the small and compact concrete structure also survived various very strong earthquakes without heavy damages. Functional scheme complies with fig.2 and photographs showing constructional details of this plant can be found in the Appendix.

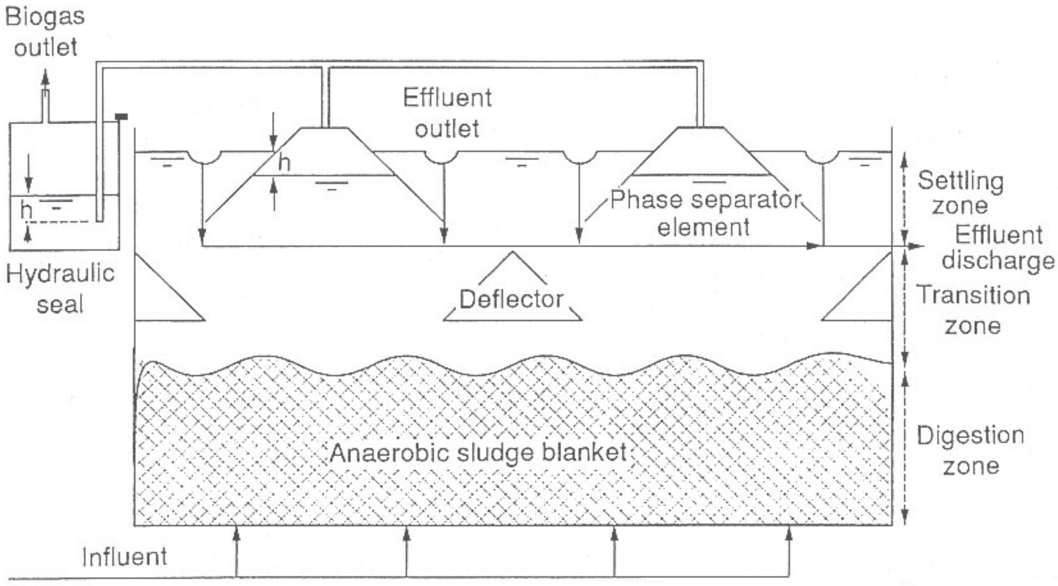

Figure 2: Schematic representation of an upflow anaerobic sludge blanket (UASB) reactor (Haandel and Lettinga, 1994).

Even though the coffee industry is currently suffering from a decline in coffee prices, this WWTP is hinting a possible way. People come to see the plant, and oral propaganda starts to show its impact already. Consequently, there have been developed several project designs for domestic UASB reactors in El Salvador since the Cafeco plant went into operation. Hence, it should only be a matter of time until the first domestic UASB will be constructed there as well.

WASTE STABILISATION POND (WSP) APPLICATIONS

Traditionally waste stabilisation ponds (WSP) are built as flow-through systems with anaerobic, facultative and one ore more maturation ponds in series (Frasinetti and van Haandel, 1996). They are widely spread all over Latin America. Due to their high requirement for land, they ideally apply for small WWTP in the range of a few hundred population equivalents (PE) up to about 50,000 PE. The upper limit is not a process or economic limit as such, it just reflects how much land is usually available. Another restriction to a simple and cheap application of WSP regards the subsoil which should preferably have a hydraulic conductivity coefficient less than 10^{-7} m/s to avoid the need for pond lining.

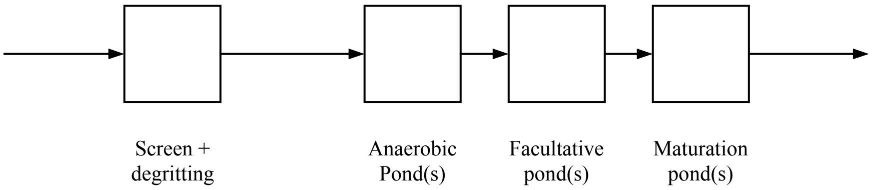

Figure 3: Schematic layout of waste stabilisation pond (WSP) system.

The advantages of WSP systems, which can be summarised as *simplicity*, *low cost* and *efficiency*, are as follows:

- *Simplicity:* WSP are simple to construct, operate and maintain. Less skilled labour is needed for pond O&M than is the case with other wastewater treatment technologies. The simplicity of WSP construction also means that flexibility in construction phasing is possible.
- *Low cost:* WSP are normally less expensive than other wastewater treatment processes. There is no need for high-cost, electromechanical equipment (which requires regular skilled maintenance), nor for a high annual consumption of electrical energy. WSP systems minimise sludge production and thus reduce the costs of, and the problems associated with, sludge handling, treatment and disposal. WSP desludging is not difficult and is done every 1-3 years, and sludge disposal can often be achieved on-site.
- *Efficiency*: Modern WSP design procedures are able to ensure compliance with the effluent quality requirements of the EU Directive on urban wastewater treatment. BOD removals > 90 % are readily obtained in a series of

well-designed ponds. WSP are additionally efficient in removing excreted pathogens. Due to their long hydraulic retention time WSP are also extremely robust.

Since the technology is thought to be relatively well-known, it is just tried to highlight typical shortcomings of WSP design and O&M by means of the photographs in the Appendix. What should be noted is the frequent lack of any pre-treatment (screening, grit removal), lack of designed by-passes, bad maintenance, scum and aquatic plant formation on the ponds and problems with sludge removal. Unfortunately very little attention is paid to parallel series of ponds, which is often indispensable if the operation should be maintained during desludging. Hence, desludging often means taking the WSP out of operation for months, discharging all wastewater meanwhile without any treatment.

TRICKLING FILTER (TF) APPLICATIONS

Trickling filters have been rather popular in Europe some decades ago, but eventually with increasing effluent standards came out of fashion. Nowadays they could experience a revival in tropical and subtropical countries due to their simplicity and good BOD removal efficiency. E.g. various TF plants for domestic sewage have been constructed towards the end of the 90ies in El Salvador, and due to the very promising results currently a considerable number of additional TF plants is in the process of design and will be constructed over the coming years. Typical plant sizes range between 5,000 PE and 50,000 PE, even though there is no natural limit for bigger plants.

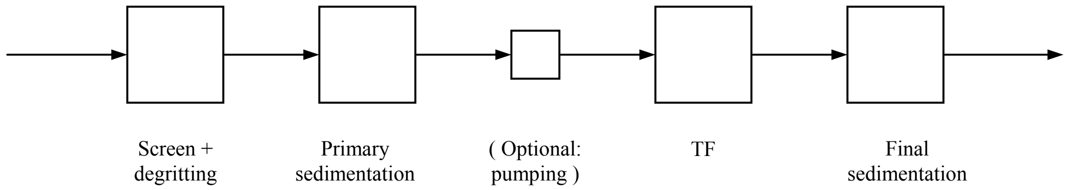

Figure 4: Schematic layout of TF.

Several photographs of TF plants in El Salvador are presented in the Appendix. Special features of these plants are: some are operated with electric energy and others completely without (mainly depending on the topography), the trickling filters themselves are frequently constructed in rectangular shape (contrary to the more common round shape) both in bricks or concrete, the sludge from the primary sedimentation and from the final sedimentation is digested together in circular open digesters at ambient temperatures, the digested sludge is delivered on to drying beds and eventually given away to local farmers who use it as manure.

ACTIVATED SLUDGE (AS) APPLICATIONS

Two main activated sludge systems can be distinguished – single tank technology with no separate clarification (mainly SBR systems) and continuous flow systems with clarification in a separate tank (secondary clarifier). Continuous flow systems provide a constant water level as an additional characteristic whereas single tank systems can be operated either with constant or variable volume (fig.5). Continuous flow activated sludge systems represent the “Northern Solution” to the municipal wastewater problem in industrialised countries while SBR-type technologies are commonly applied in industrial wastewater treatment. Also in the Latin American region especially where treatment systems are required to produce a low solids effluent for urban reuse and plant location do not allow odour risks activated sludge systems have been applied. For this region system variations have been developed in order to simplify the operational scheme and the equipment (e.g. cyclic flow-through activated sludge system on Margarita Island in Venezuela; Lansdell, 1998).

Between the two main systems with time or space control so called combined systems are situated which try to combine features from both strategies (fig.5). Biodenitro and Biocos are two examples for combined systems both operated periodically. The Biodenitro system (Christensen, 1975) shows alternating flow pattern and the aeration is switched from one reactor to the other. So the biological reactors are operated periodically and the settler continuously. A Biocos system is operated just the other way round: Continuous operation of the biological reactor and periodic operation of the settling compartments.

A Biocos plant achieves free flow at constant water levels by a configuration of three reactors: The influent flow is fed to an aerated reactor – the B-reactor, which is followed by two parallel SU-reactors. The SU-reactors are operated according to the single-tank-technology. The time control of the Biocos-system provides a settling phase and a discharge phase in order to withdraw supernatant water from the SU-reactors. Due to alternating operation the effluent valve of one of the two SU-reactors is open and enables the influent flow to displace supernatant water. During this period activated sludge is disposed from the B-reactor to one SU-reactor. Therefore the sludge concentrations need an equalisation after each discharge phase. During the mixing phase the content of the B-reactor is pumped into the SU-reactor near the bottom causing a return flow at the surface until the circulation has balanced the concentrations. In the SU-reactors endogenous denitrification takes place beneath the settling sludge blanket because of high sludge concentrations and a lack of easily degradable carbon.

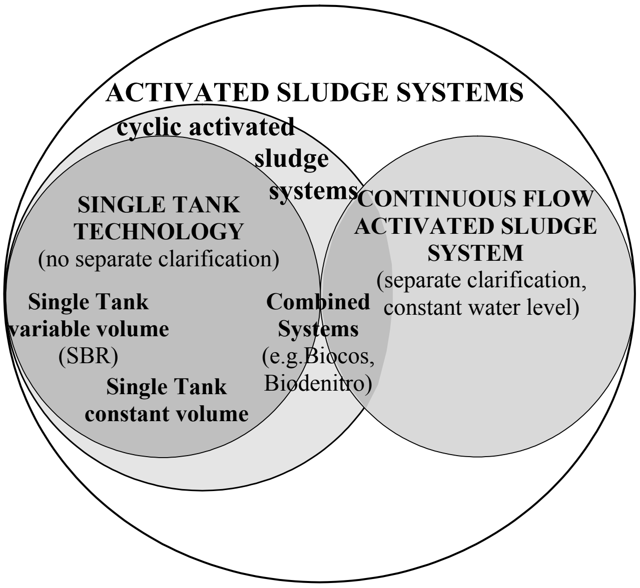

Figure 5: Classification of activated sludge systems with Biocos combining features from single tank technology and continuous flow systems (Wett and Ingerle, 2001)

The Biocos system has been applied in the Latin American region to treat domestic wastewater of some hotels and vacation resorts in the Dominican Republic, e.g. the 2000 PE plant Cofresi (Appendix). The aerobic F/M ratio for full nitrification at temperatures > 25°C is designed at 0.2 kg BOD / kg SS.d. Compared to European conditions with wastewater temperatures around 8 to 10 °C in the winter season this means a reduction of the sludge retention time SRT from 10 to about 5 days. Still the measured effluent quality agrees with European standards (≤ 75 mg/L COD, ≤ 20 mg/L BOD, ≤ 5 mg/L NH4-N). The energy demand amounts to 3.5 W/PE and the specific volume is about 0.15 m3/PE.

The mechanical equipment aims at simplicity: All actions are operated by the air compression unit which provides pressurized air for the fine bubble diffusers in the B-reactor and the hydraulic siphons for the recycle flow and the waste sludge withdrawal (mammoth pump principle). The airflow to these facilities is directed by magnetic valves which are controlled by a central control unit. Hence there are no electrical or mechanical devices beneath the water surface of the reactors in order to minimise maintenance and to increase operation safety.

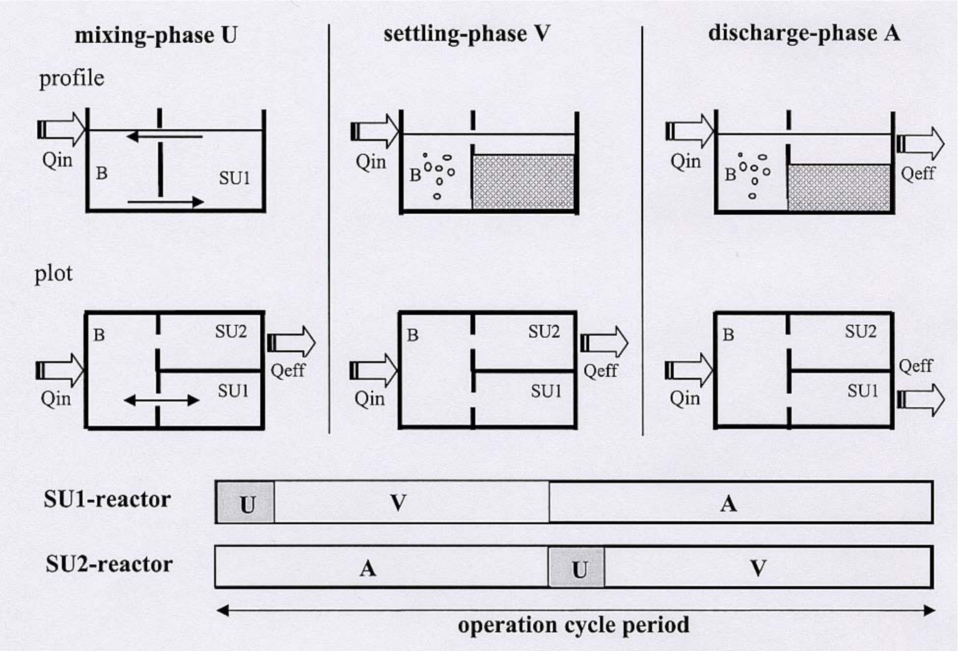

Figure 6: Flow- and operational scheme of a Biocos plant

ECONOMIC COMPARISON

	UASB + pond	WSP	TF	AS
LATIN AMERICA				
Columbia, 160,000 PE (Lettinga et al., 2001)	IC = 16 $/PE OMC= 0.7 $/PE/a			
Venezuela, 1,000,000 PE 50,000 PE (Lansdell, 1998)		IC = 4 $/PE		 IC < 20 $/PE
El Salvador, 5,000 PE (Beller Consult, 2000)	IC = 110 $/PE		IC = 120 $/PE	
Dominican Republic, 2000 PE				IC ≈ 150 $/PE
Colombia, 4,500 PE (Peña et al., 2000) (without land cost)	UASB only: IC = 19.5 $/PE OMC= 9.4 $/PE/a	anaerobic pond: IC = 16.2 $/PE OMC= 5.8 $/PE/a		
EUROPE				
Germany, valid for rural area + about 500 PE (Mara and Pearson, 1998)		IC = 350 $/PE	IC = 750 $/PE	IC = 1,000 $/PE
Germany; about 1,000 PE (MLUR, Brandenburg, 2003)		IC = 250 $/PE		
Germany; about 10,000 PE (MLUR, Brandenburg, 2003)				OMC = 35 $/PE/a
Germany; about 50,000 PE (MLUR, Brandenburg, 2003)				IC = 300 $/PE
OTHER				
Yemen, 250,000 PE (Arthur 1983)		IC = 23 $/PE OMC= 0.8 $/PE/a	IC = 31 $/PE OMC = 3.4 $/PE/a	

IC … investment cost, OMC … operation and maintenance cost

Table 2: Investment costs and specific annual costs for operation and maintenance of different exemplified wastewater treatment systems.

The above table presents an arbitrary compilation of cost figures, which of course always depend heavily on local conditions (e.g. size or design load, national average price level, effluent requirements, topography, temperature, etc.). Nevertheless certain trends can be derived, i.e.:

- UASB can often compete economically with supposedly "unbeatable cheap" WSP.
- If land-saving aerobic post-treatment of anaerobic systems is required, then TF usually fare better than AS – especially in terms of O&M.
- Since most prices are given exclusively land costs AS (as the most compact one-step treatment) might become competitive under packed conditions.

CONCLUSIONS

Anaerobic systems prove to be an excellent treatment technology for many areas of Latin America. In future the traditional system of WSP shall definitely compete more and more with UASB systems. Post-treatment still requires aerobic systems, which e.g. can be ponds, trickling filters or activated sludge plants. The bigger the plants, the more economical it might combine these technologies. Several projects are going that way at present. Just to name 2 examples: Tegucigalpa, capital of Honduras, is planning an UASB-plant with aerobic post-treatment, and Managua, capital of Nicaragua, has just released a functional tender for a 1.1 million PE plant. The basic solution recommended in the latter is a combination of anaerobic ponds with subsequent trickling filters (see Appendix). The final outcome of these two projects might not be 100 % fixed yet, and it might be just a small drop in a big continent, but it points the future way of combining anaerobic with aerobic technologies in Latin America.

Europe, on the other hand, due to its lack of warm climate and land as well, will most likely continue on its predominantly activated sludge path.

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APPENDIX

UASB reactor for Cafeco S.A. de C.V., El Salvador
About 100,000 PE seasonal organic load from coffee processing

View of the compact UASB reactor.

Influent flow distributed at the top of the reactor (sliders + horizontal pipes and …

… fed to the bottom of the reactor via vertical pipes.

Waste stabilisation pond WSP El Paraíso, Honduras

Anaerobic pond
Sludge accumulation around the inlet due to lack of any pre-treatment

Anaerobic pond
Nobody thought about before how to desludge the pond.

Maturation pond
Poor maintenance + poor hydraulics (short circuit flow)

Waste stabilisation pond WSP Nacaome, Honduras

Facultative pond
Poor embankment protection system.
Floating algae.

WSP Catacamas, Honduras

Maturation pond
Scum and grease accumulation near the outlet

Facultative pond
Anaerobic conditions prevail, consequently proliferation of rose red sulphur bacteria

Biocos- wwtp Sun Village Hotel (2000 PE),
Cofresi, Dominican Republic

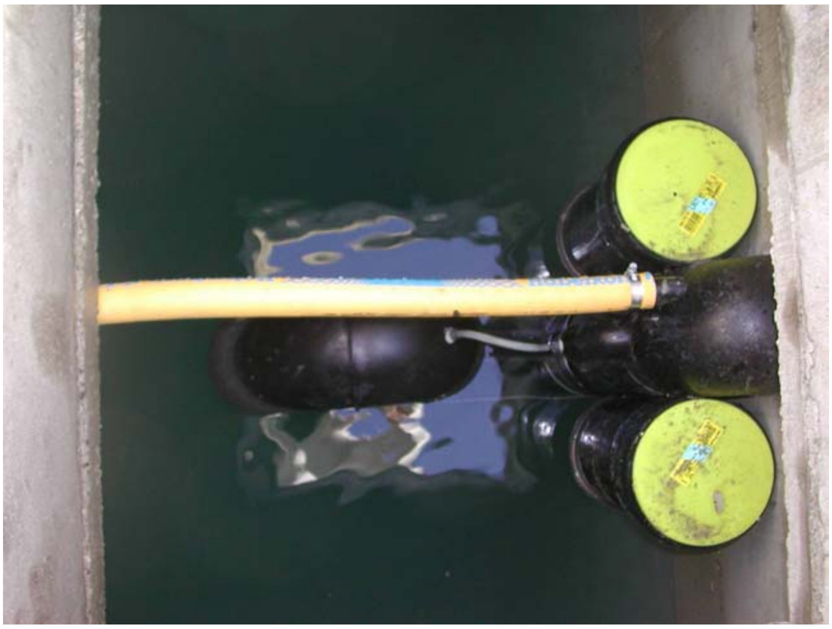
Above: Covered Biocos plant to avoid any visual- and odour nuisance near the hotel

Left: High effluent quality achieving > 95 % organic load reduction and advanced nitrogen elimination

**Biocos- wwtp Sun Village Hotel (2000 PE),
Cofresi, Dominican Republic**

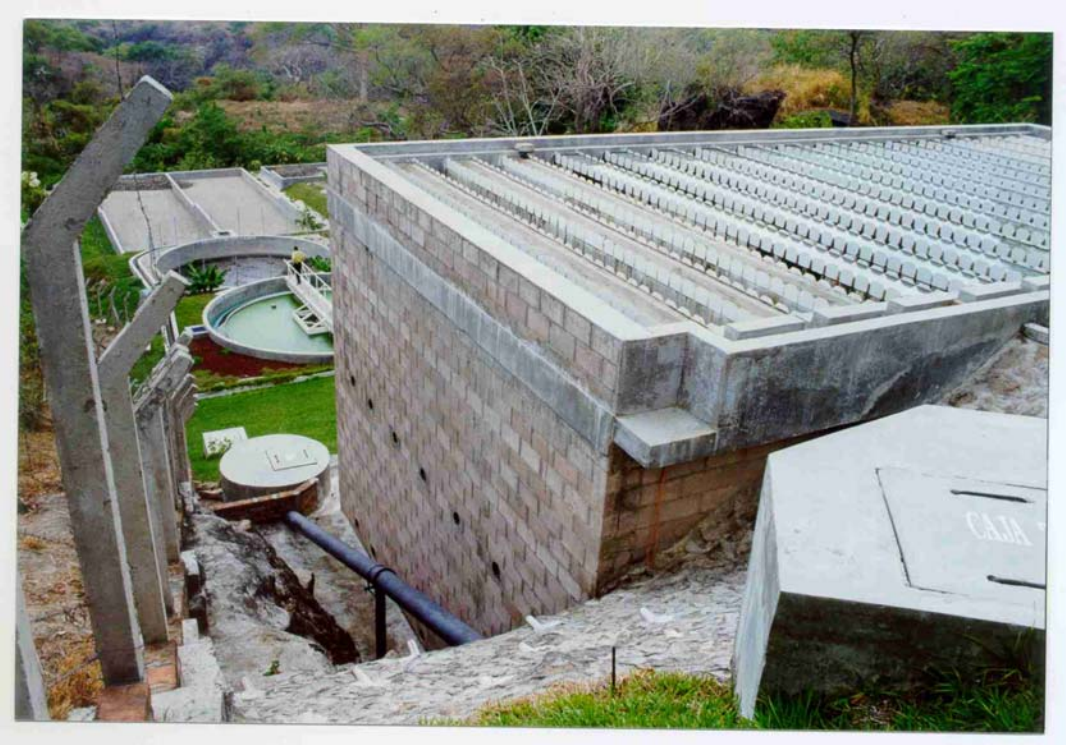
3 blower units - each 3.5 kW for 1000 PE and one unit stand-by

Control unit – storage programmable control in the middle and electromagnetic valves directing pressurized air to the individual consumers (fine bubbles aerators, airlift pumps for clarified water and waste sludge)



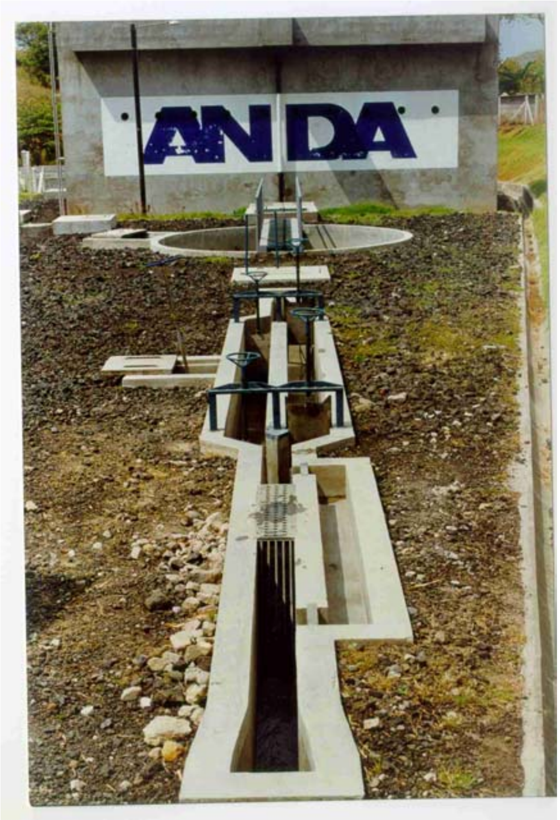
Effluent discharge in the sedimentation and circulation tank operated with pressurized air - view from above

Trickling filter TF San Juan Talpa (8,000 PE) , El Salvador - a TF plant without any electric energy



From right to left: trickling filter, sedimentation tank, sludge digester, drying beds

TF San Jose Villanueva (3,000 PE), El Salvador - electric energy needed only for supplying the TF

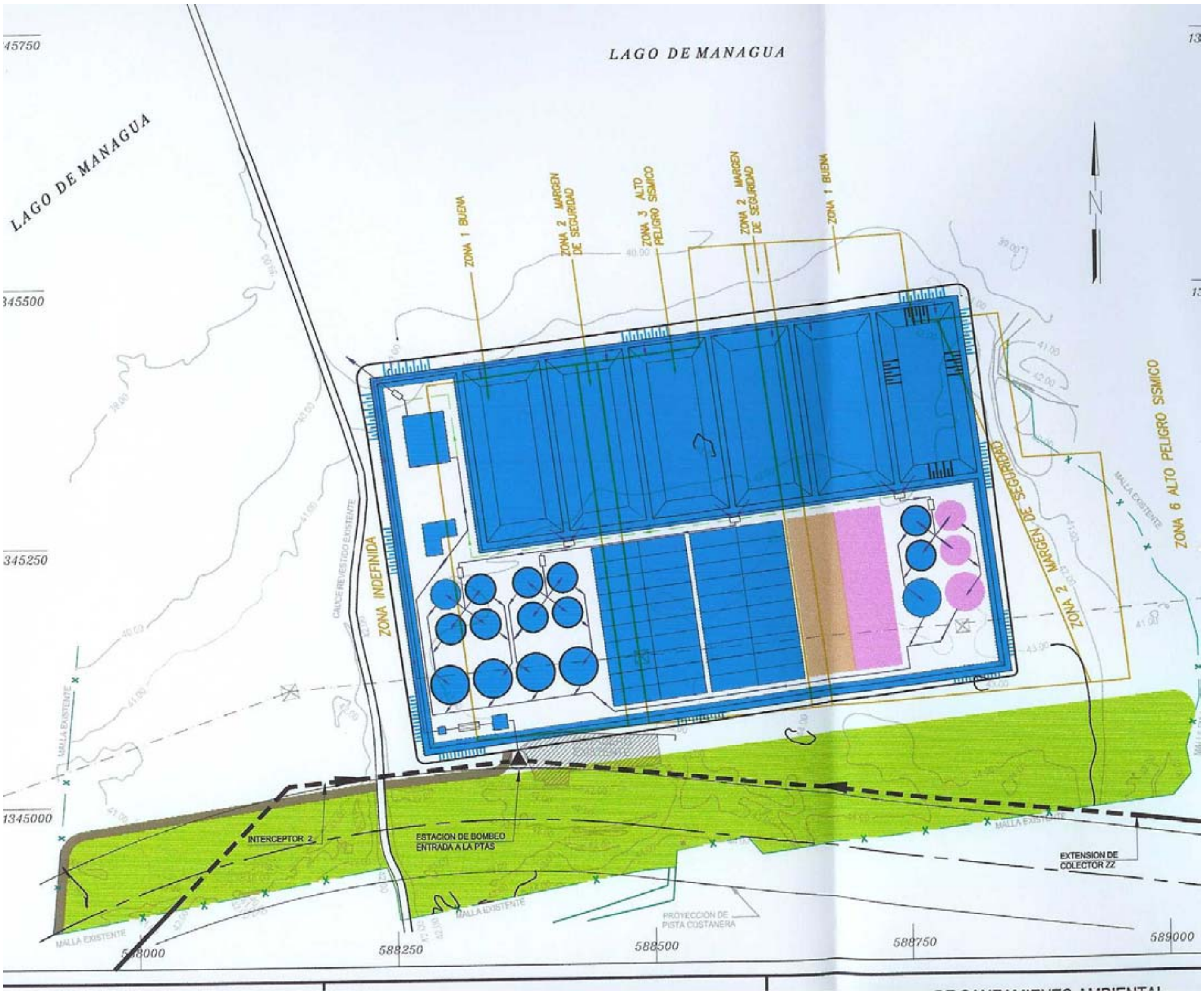


Above: on the head of the trickling filter TF
(drying beds in the back)

Left: screen, grit chamber, primary sedimentation, TF

WWTP Managua (1.1 million PE), Nicaragua *

Combination of 6 parallel anaerobic ponds with trickling filters (and secondary clarifiers) as a post treatment and drying beds as sludge treatment.



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