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Water & Sanitation in Developing Countries

DESIGN CONSIDERATIONS OF CONSTRUCTED WETLANDS FOR SEPTAGE TREATMENT AT THE AIT PILOT PLANT

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ABSTRACT

Sludge or septage treatment technologies as are used in larger treatment systems in industrialized countries (e.g. mixed anaerobic digesters; chemically aided, mechanical dewatering/drying systems) proved to usually not be sustainable in developing countries. Cost of investment and operation of such systems are typically beyond economic and financial affordability. The constructed wetland system, a sand-gravel filter cultivated with emergent plants such as cattails, has already proven to be an efficient and low-cost technology for sludge and wastewater treatment. To investigate and evaluate the potential of this technology also for septage treatment, the vertical-flow pilot plants were constructed at AIT and planting with narrow-leave cattails (*Typha augustifolia*). Design considerations such as removal mechanisms and treatment components of the AIT pilot-plants were described in the context.

INTRODUCTION

Backgrounds

In most rural and urban areas of developing countries, where sewerage systems are not available, human excreta are commonly disposed of in on-site systems such as septic tanks, cesspools, or pit latrines. Septage and other types of faecal sludges produced in these units need to be periodically removed. They are characterized by a high solids, organic and enteric microorganism content, often large quantities of grit and grease, a great capacity to foam upon agitation, and often poor settling and dewatering characteristics (Polprasert, 1996). Discharge of the untreated septage to watercourses or land may result in environmental degradation, serious public health risks, unpleasant odors and eyesore (Strauss *et al.*, 1997).

Constructed wetlands (CW) are man-made systems aiming at simulating the treatment processes in natural wetlands by cultivating the emergent plants e.g. reeds (*Phragmites*), bulrushes (*Scirpus*), and cattails (*Typha*) on sand, gravel, or soil media. Based on investigations of pilot and field-scale systems, CW have been proven to constitute a promising treatment option characterized by low investment, operation and maintenance costs (Kadlec and Knight, 1995; Polprasert, 1996, and Copper *et al.*, 1995). Therefore, utilization of CW in waste treatment and recycling is currently of interest including their ancillary benefits such as supporting primary production and enhancement of wildlife habitats. For several years, a number of CW systems have been employed to treat various kinds of wastewaters including, more recently, sludge from conventional treatment plants (Heinss and Koottetep, 1998).

Two types of CW have been developed for wastewater treatment: horizontal-flow systems - free water surface (FWS) and subsurface flow (SF) - whereas a vertical-flow (VF) system is generally used for sludge or septage treatment. An FWS system consists of parallel basins or channels with relatively impermeable bottom layers and the water depth is maintained at 0.1-0.6 m above the soil surface. An SF system has the similar configuration to the FWS except the water depth is maintained at or below the soil surface. In both FWS and SF systems, the wastewater flows horizontally along the wetland substrata and/or surface water at which several treatment mechanisms are taking place.

Contrary to flow pattern in FWS and SF systems, a VF unit manipulates flow direction to be downward from sand surface to percolate-drainage system, typically installed beneath the CW beds. The alleged advantage of CW over conventional, unplanted sludge drying beds is the much lower frequency of dewatered sludge removal from the bed, allowing for several years of sludge accumulation prior to bed emptying. The principle behind the system is that the roots and rhizomes open up the sludge mass and provide channels to improve the drainage of water. It is also likely that there will be some evapotranspiration produced by the wetland plants, resulting in the better sludge dewatering. In addition, the percolating liquid is subjected to a longer retention time within the bed, enabling nitrification and higher removal efficiencies within the liquid.

Treatment Mechanisms

Solids Removal

Because substrata of the VF system typically contain soil, sand and/or gravel, which is similar to that of a granular-medium filter (Metcalf & Eddy, 1991), the principal mechanisms that contribute to the removal of solids should include:

1. Straining
    a) Mechanical – Particles larger than the pore space of the filtering medium are strained out mechanically.
    b) Chance contact – Particles smaller than the pore space are trapped within the filter by chance contact
2. Sedimentation – Particles settle on the filtering medium within the filter

3. Impaction – Heavy particles will not follow the flow streamlines

4. Interception – Many particles that move along in the streamline are removed when they come into contact with the filtering medium

In addition, during the particle transport through the filtering media, there could be other removal mechanisms such as adhesion, chemical and physical adsorption, and flocculation, depending on characteristics of the particles and media.

Apart from the above solid removal mechanisms, another possible advantage of the VF constructed wetlands to a sludge drying beds is that the plant evapotranpiration is beneficial to the sludge dewatering process. Besides, the plant roots and rhizomes open up sludge mass and provide channels to improve drainage of water (Cooper *et al.*, 1996).

Organic Removal

In the HF constructed wetlands treating wastewater, organic removal mechanisms depend on various reactions and interactions as shown in Fig. 1. Because flow direction of the VF constructed wetlands are downward through the substrata, the principal mechanisms responsible for removal of organic likely include:

(1) filtration/sedimentation of organic particulate;
(2) organic decomposition; and
(3) aerobic/anaerobic biodegradation.

However, due to the complicated reactions/interactions among various types of micro-biota and plants as well as the lack of comprehensive research in the VF constructed wetlands, the removal mechanisms are not yet well understood.

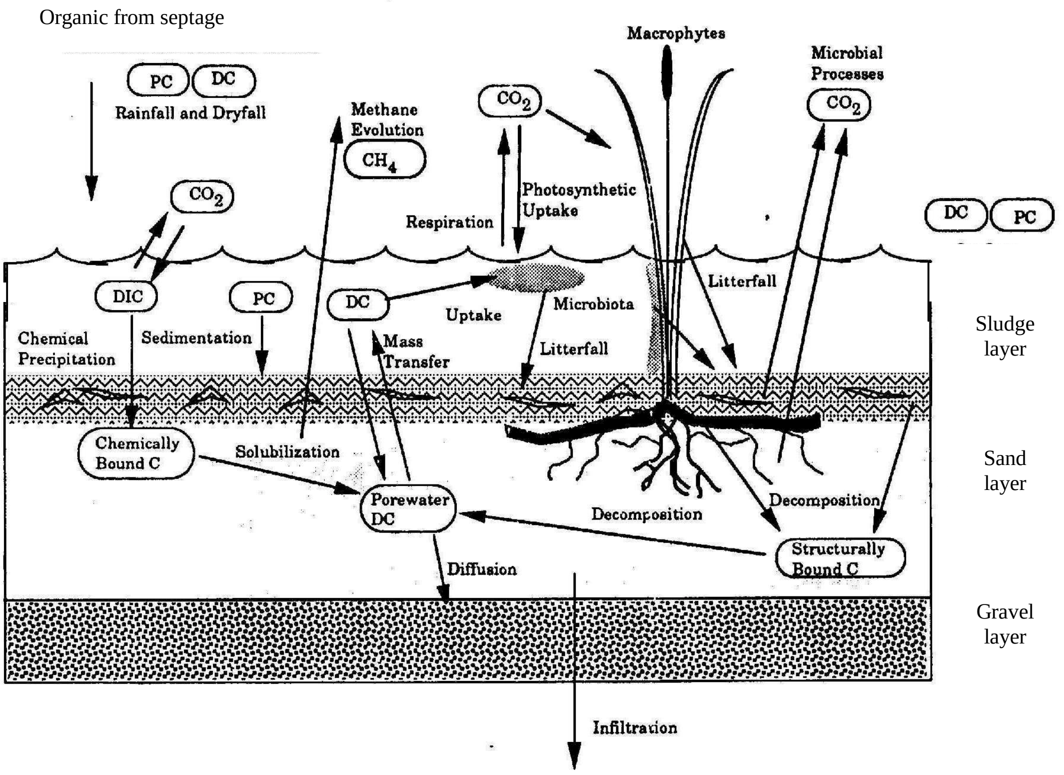

Figure 1. Organic removal mechanisms in constructed wetlands
(Adapted from Kadlec & Knight, 1995)

Nitrogen removal

Major treatment mechanisms for nitrogen (N) removal in the constructed wetlands consist of N plant uptake, nitrification/denitrification, NH_3 volatilization, filtration/sedimentation of particulate N and N adsorption onto substrata. N removal mechanisms also involve several interactions and reactions in the constructed wetlands as shown in Fig. 2. Details of the N removal mechanisms are explained in many literatures for decades.

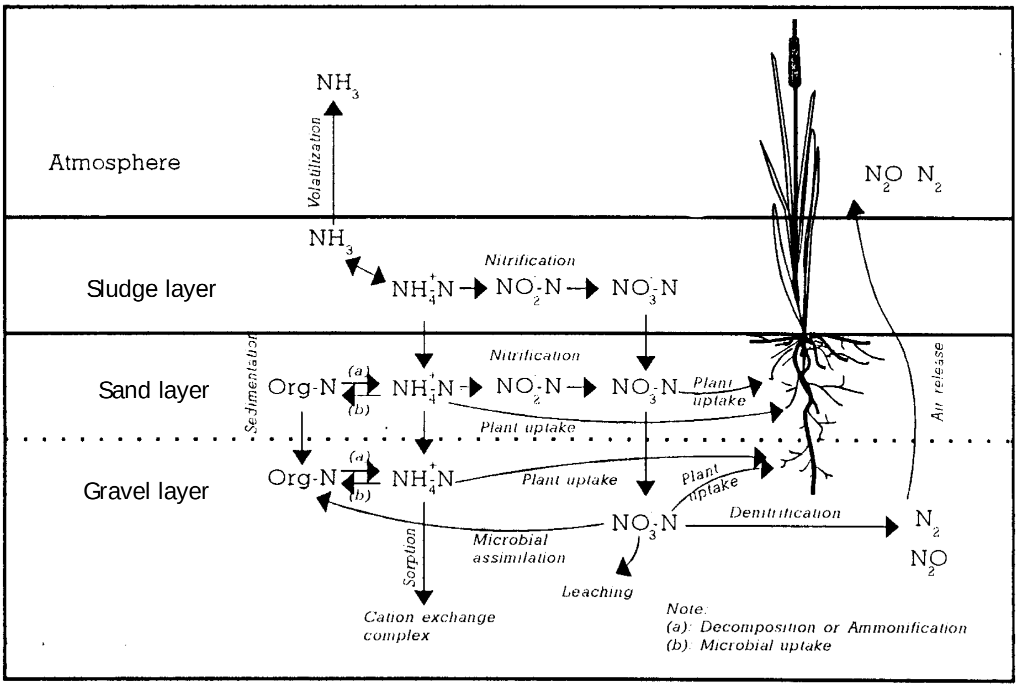

Figure 2. N removal mechanisms in constructed wetlands
(Adapted from Kadlec & Knight, 1995)

In treating septage having high TKN and NH_3 contents, N plant uptake may not play an important role in removal of N in the constructed wetlands. It is probably because N requirement of the emergent plants is generally limited to some extent depending on plant species. For example, N contents in the tropical cattails are in the range of 1-2% of dry plant biomass (Kadlec and Knight, 1995). With the same reasons as explained above, we are unlikely be able to identify the major N removal mechanisms except the N mass balance analyses.

OBJECTIVES

Septage treatment in VF constructed wetlands has never been tested prior to the AIT/EAWAG collaborative project, except in laboratory -scale experiments at Cemagref in Lyon, France (Liénard and Payrastre, 1996). Given the successful application of CW in sewage treatment plant sludge dewatering, EAWAG and AIT set up a research collaboration on "*Septage Treatment by CW and Attached-growth Waste Stabilisation Ponds*" in 1996 to test the basic suitability of this treatment option and to establish design and operational guidelines. The field experiments are scheduled to last from 1997-1999.

The specific objectives of this field research are

i) to determine the treatment performance of the CW and effects of the applied septage on the cattail plants;

ii) to determine the suitability and optimum growth requirements of cattails; and

iii) to find out the optimum design criteria and operating conditions of the CW systems.

DESIGNS OF CONSTRUCTED WETLANDS - AIT PILOT-PLANT

Treatment Components

Configurations and Dimensions

Based on the site and literature surveys of the VF constructed wetlands treating sludge in Europe (Heinss and Koottatep, 1998), it was evident that most of the constructed wetland units are independent of length to width ratio. The distribution of sludge onto the surface of constructed wetlands would play more important role in the unit operations. The AIT pilot plants were then figured to have square surfaces in order that septage can be uniformly distributed by moving hose-nozzle around the units.

In the experiments of Limsuwan (1997) and Pinsakul (1997), two laboratory-scale units were modified from sand drying beds, each having surface area of 2 x 2 m and made from reinforced concrete. The Bangkok septage was manually loaded by a feeding hose connected to the septage pump. The AIT pilot plants comprise of three VF units, each with a surface area of 5 x 5 m and lined with ferro-cement as shown in Fig. 3 and 4. To reduce concrete works and other supports, the pilot plants were designed to have inclined bunkers with a slope of 1:1.

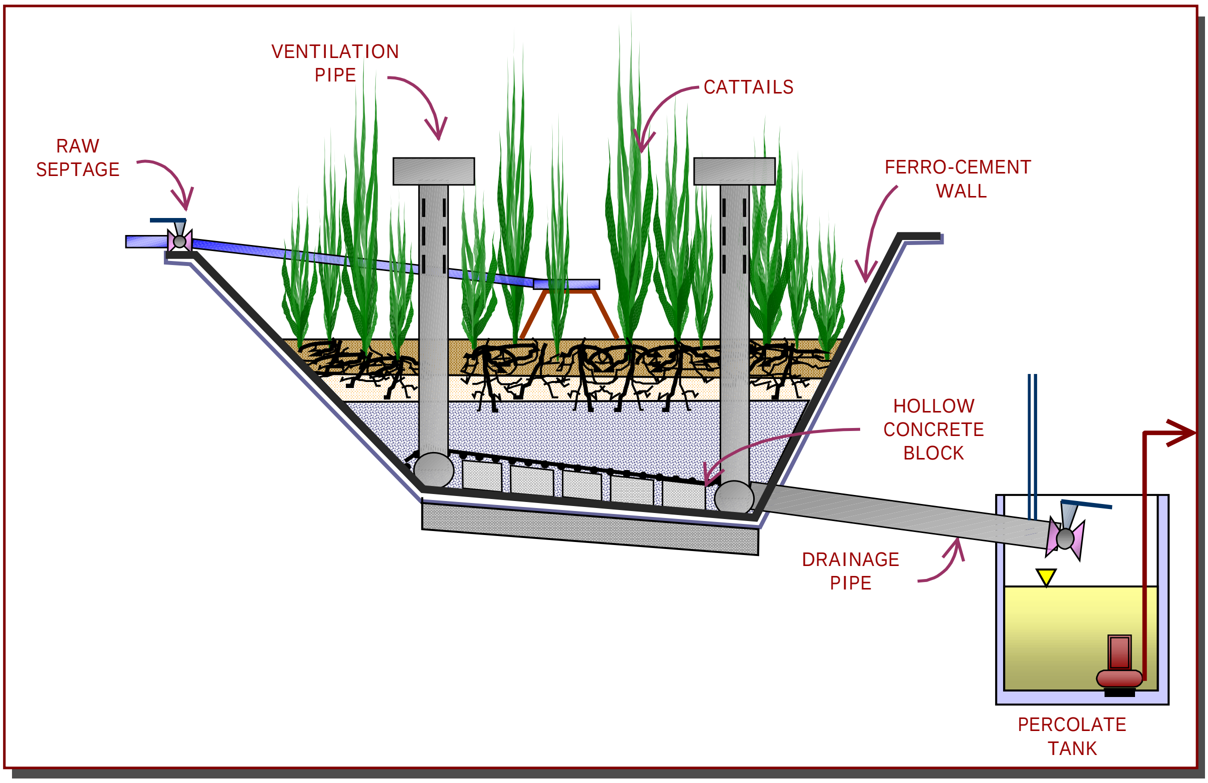

Figure 3. Schematic diagram of AIT pilot plant

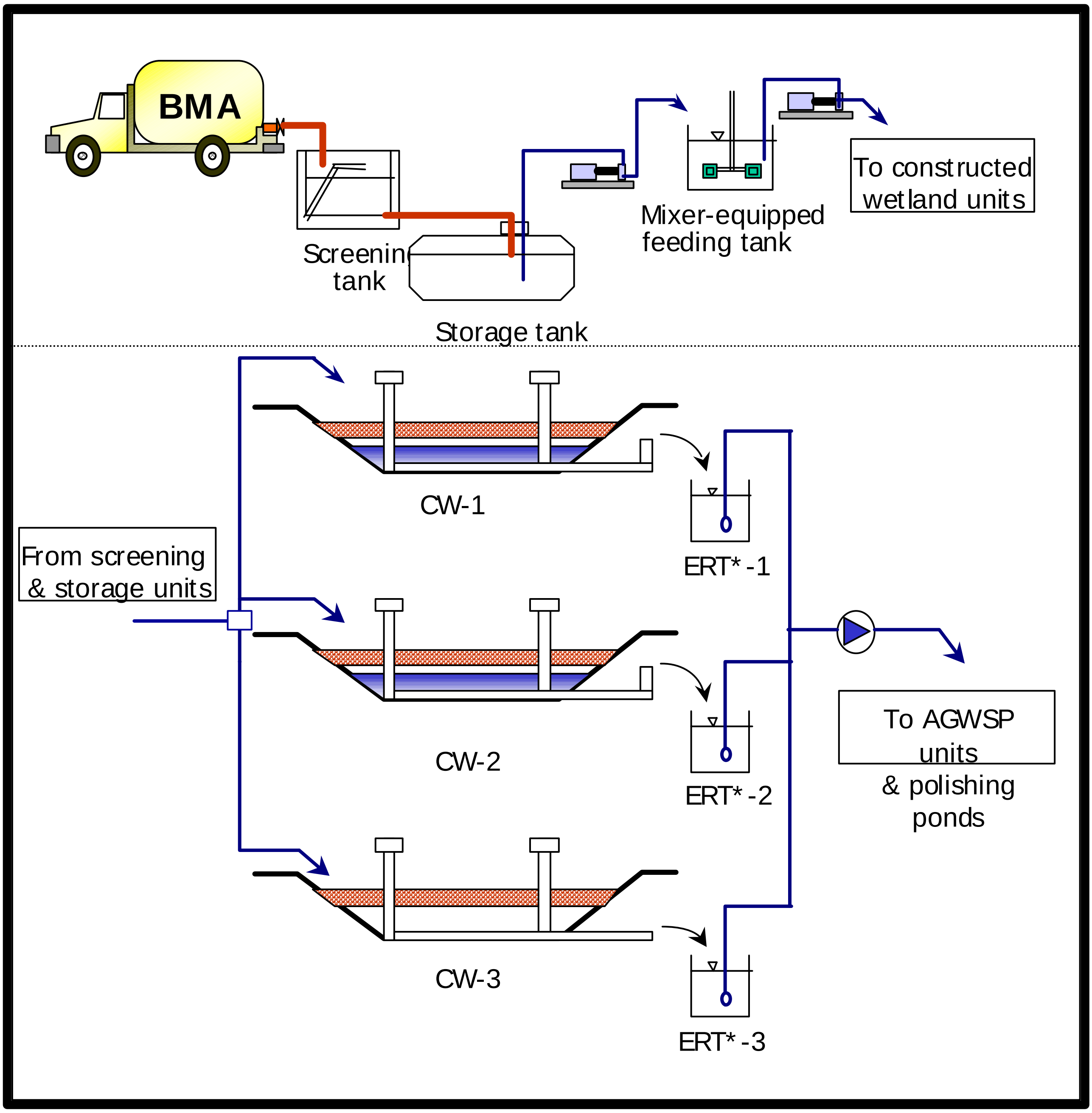

Figure 4. Overview of AIT pilot plant

Substrata

Based on the suggestions drawn by Cooper *et al.* (1996), the substrata of VF constructed wetlands planting with reeds should have a depth of 80 cm with a 70-cm graded gravel layer and topped off with 10-cm sharp sand. Because length of the cattail roots is only about 30-40 cm, relatively shorter than reeds (50-60 cm), the substrata depth in these experiments was designed to be 65 cm. A 10-cm layer of fine sand, 15-cm layer of small gravel, and 40-cm layer of large gravel from top to bottom were used as substrata in each pilot plant. In each pilot plant, a free board of 1 m was allowed for accumulation of the dewatered septage.

Vegetation

Due to reeds are an indigenous species in temperate countries, they are normally vegetated in the constructed wetlands, so-called "reed beds". In Thailand, the cattail plants are indigenous species and growing better than reeds in most wetland areas. The narrow-leave cattails (*Typha augustifolia*) were thus planted in each pilot unit at the initial density of 40-50 shoots/m^2. The cattail plants were collected from the AIT natural wetlands and transplanting to the pilot plants.

Underdrain and Ventilation System

The bed support and drainage system consists of hollow concrete blocks, each with a dimension of 20 x 40 x 16 cm (width x length x hollow space), and perforated PVC pipes with a diameter of 20 cm at the bottom. Mounted on the drainage system are ventilation pipes of the same diameter and extending approximately 1 m over the top edge of the units. Natural draught ventilation is required to avoid anaerobic conditions in the root zone and, hence, plant damage. The percolate from the CW units is collected in 1-m diameter concrete receiving tanks with 1.5 m of height.

OPERATING CONDITIONS

Based on the investigations of Cooper *et al.* (1996), the suggested solid loading rates (SLR) for reed beds treating activated sludge in Europe range from 30 – 80 kg total solids (TS)/m^2.yr and sludge loading frequency should be once in a week. In tropical regions, it is expected that the VF constructed wetlands could be loaded with sludge at the higher SLR. Therefore, septage was loaded at the SLR range of 40 – 250 kg TS/m^2.yr in the laboratory-scale VF experiments conducted by Limsuwan (1997) and Pinsakul (1997) at the Environmental Research Station of AIT. The results obtained from these laboratory-scale experiments suggested the SLR of 80 – 125 kg TS/m^2.yr and twice-a-week septage loading frequency.

The AIT pilot plants were fed with Bangkok septage, collected from a 12-m^3 BMA collecting truck (Fig. 5), and subjected to the operating conditions as shown in Table 1. To remove garbage and rags the raw septage was screened at a bar screen unit and then homogenized at a 4-m^3 mixing tank before feeding to the pilot plants.

Table 1. Operating conditions of the pilot-scale CW units

Run	SLR$^+$ (kgTS/m^2.yr) Unit-1	Unit-2	Unit-3	Percolate ponding *	Frequency of septage application	Periods of Operation
I	250	125	80	No	twice-a-week	Apr. 97 – May 97
II	250	125	80	No	once-a week	May 97 – Jul. 97
III	250	125	80	No	twice-a week	Aug. 97 – Dec. 97
IV	500	250	160	No	twice-a-week	Dec. 97 – Jan. 98
V	500	250	160	No	once-a week	Feb. 98 – Mar. 98
VI	250[a]	250[b]	250[c]	Yes	once-a week	Apr. 98 – Dec. 98

$^+$ SLR = Solids loading rate

* Percolate was retained 10 cm below the dried septage layer in the CW units

[a] ponding period = 6 days, [b] ponding period = 2 days, [c] no ponding

Figure 5. Septage collection in Bangkok and discharging to AIT pilot plant

During the course of experiments, the operating conditions have been varied according to the operational experiences and results obtained from each experimental run. Details of the variation are explained in the context of paper on "Results of the 2-Year Observations and Lessons Learnt from Operating Experience of the AIT Constructed Wetlands".

MONITORING PARAMETERS

Samples collected from the pilot-plants at different operating conditions were measured for the contents of TS, TVS, SS, VSS, TCOD, DCOD, TKN, NH_3, NO_3, fecal coliforms as well as some heavy metals. Analytical methods for these parameters were according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA, WPCF, 1992). In addition, the septage samples were tested for numbers of helminth eggs as hygienic indicator.

The experimental results and discussions obtained from the above operating conditions are illustrated in the following papers.

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