



ONSITE WASTEWATER DIFFERENTIABLE TREATMENT SYSTEM (OWDTS), AN ECOLOGICAL SANITATION ALTERNATIVE FOR DEVELOPING COUNTRIES

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ABSTRACT

In this paper, the Onsite Wastewater Differentiable Treatment System (OWDTS) is presented as an ecological sanitation alternative for developing countries and supported by principles such as dry ecological sanitation, ecologically sustainable development, recycle of resources (water and nutrients contained in toilet wastes), conservation of water resources, protection of public health and the prevention of public health risk. The OWDTs constitutes a new approach for improving the traditional onsite wastewater treatment systems and it is proposed based on a differentiable management and treatment of household wastewater effluents. Three fractions of household wastewater have been differentiated, reduced-volume blackwater, higher-load graywater and lower-load graywater. Based on this differentiation, different treatment processes required for each fraction are discussed. Aerobic biodegradation using sawdust as a matrix is an essential process for treating the toilet wastes (reduced-volume blackwater). In case of graywater, a sketch of treatment processes is pointed out. Membrane technology arises as a candidate alternative for treating higher-load gray water, whereas natural soil treatment system is considered for the lower-load graywater. However, both processes need to be deeply studied. A brief overview of the undertaken research for supporting scientifically the OWDTs is included.

Keywords: Bio-toilet; higher-load graywater; lower-load graywater; onsite wastewater differentiable treatment system (OWDTs), reduced-volume blackwater.

INTRODUCTION

According to WHO estimates, approximately 80% of all diseases occurring in many developing countries, and one third of all deaths, are attributed to polluted water and hygiene deficiencies. Despite this, only about 5% of the world's wastewater is treated. More than one billion people have no access to clean water, and even fewer benefit from sound sanitation. As a consequence of this lack of sanitation, 3.3 million people die annually from diarrhoeal diseases, out of 3.5 billion infected (WHO, 1996). One of the main reasons for this situation is the high cost of current water-borne sanitation techniques and methods.

On the other hand, centralized water-borne sewage systems leading to multistage sewage treatment plants seem to be unsuitable as a blanket solution for developing countries, particularly in arid zones, due to their enormous investment,

operating and maintenance costs, their high water consumption and other drawbacks. These centralized systems are also running into criticism in developed countries because of economic and ecological issues. However, conventional individual disposal systems also make poor alternatives, especially in view of increasing population densities and the substantial groundwater contamination they cause (Werner, 2000). Under these considerations, Onsite Wastewater Differentiable Treatment System (OWDTS), a new holistic approach for improving the traditional onsite wastewater treatment systems, aims to be a reliable ecological sanitation solution in developing countries. The OWDTS is proposed based on a differentiable management and treatment of household wastewater effluents.

The wastewater effluent from a household or group of households is made up of contributions from various appliances, such as WC, kitchen sink, washbasin, bath, shower, and washing machine. WC represents the highest contribution to the wastewater in terms of volume and load for five out of the six determinants, the exception being the nitrate. The kitchen sink is the most important appliance for nitrate production and second in production of COD, TSS and PO₄-P (Almeida et al., 1999). Traditionally, wastewater effluent from a household has been divided into two fractions, blackwater (toilet wastes) and graywater (kitchen sink, wash basin, bath, shower, and washing machine). Elimination of blackwater from the residential wastewater stream by using non-water carriage toilet will reduce the mass of COD, TSS, nitrogen and phosphorous in the remaining wastewater stream (graywater), thus allowing smaller treatment units (Ayres Associates, 1998).

In this paper, the main concepts and expected benefits associated to the implementation of the OWDTS are presented as an ecological sanitation alternative for the treatment of domestic wastewater and a holistic approach for developing countries. Additionally, a brief overview of the undertaken research for supporting scientifically the OWDTS is included.

CONCEPTUALIZATION OF THE ONSITE WASTEWATER DIFFERENTIABLE TREATMENT SYSTEM

Centralized water/wastewater management systems.- Despite of positive aspects of the centralized water-wastewater management systems (reliable and efficient management and control), these have disadvantages which should not be neglected, especially in view of the integrated product policy (IPP) concept adopted by the EU (Wilderer, 2001). The cost benefits of central systems diminish when the costs of building and maintaining the distribution and collection system are taken into account. Surveys conducted in many cities have revealed extensive leakage causing infiltration of groundwater and exfiltration of wastewater and subsequent groundwater pollution. Estimating the cost of worldwide implementation of centralized systems, it becomes evident that the capacity of the global money market would not be sufficient to cover the need for investment capital. It is hard to believe that centralized systems are seen as the best solution for problems in developing countries, especially in mega-cities. There are further problems to be considered when assessing centralized systems.

Decentralized water/wastewater management systems.- In general, the treatment results achieved in practice by the decentralized water-wastewater management systems are not satisfactory when the IPP-relevant criteria (low consumption of resources, long-lasting technology, advance treatment requirements) are used as a measure (Wilderer, 2001). There are three major concerns:

- a) The effluent quality is mostly low and rarely allows safe reuse of water.
- b) Treatment plants are not properly operated.
- c) Plants are difficult to supervise and control by water authorities.

Onsite wastewater treatment systems (OWTS).- Traditional onsite wastewater treatment systems have experienced two types of failure, operational and functional; the first, when the system does not remove wastewater from the home, and the last one, when the system continues to remove wastewater but does not properly treat the water prior to discharge into the environment. The inappropriate use and disposal of wastes from OWTS can have a number of adverse impacts that would include: spread of diseases, contamination of ground and surface water, degradation of soil and vegetation, decrease in amenity due to odors and insects, and potential litigation (Ward and Englehardt, 1999).

Onsite wastewater differentiable treatment system (OWDTS).- To overcome the shortcomings, disadvantages or weakpoints of the centralized, decentralized and traditional onsite water/wastewater management systems and to lead to the way towards a holistic approach for the domestic water/wastewater management, the OWDTS was introduced (Lopez *et al.*, 2001). The management of the OWDTS is supported by environmental, economical and health principles such as: ecological sanitation, ecologically sustainable development, resources recycle (nutrients and water), integrated water/wastewater management, conservation of water resources, protection of public health and the prevention of public health risk. Figure 1 shows a hypothetical model for onsite wastewater differentiable treatment system. In this system, the fractioning of household wastewater into three types is essential. Thus, reduced-volume blackwater, higher-load and lower-load graywater are new concepts that are introduced in this model, see Table 1. Here, the treatment of blackwater conceives an important change in the traditional way of using the WC; in other words, the use of water in the WC is thought just to clean the toilet, not to transport the toilet wastes; this is a very important change that it is possible by using a bio-toilet (dry-toilet).

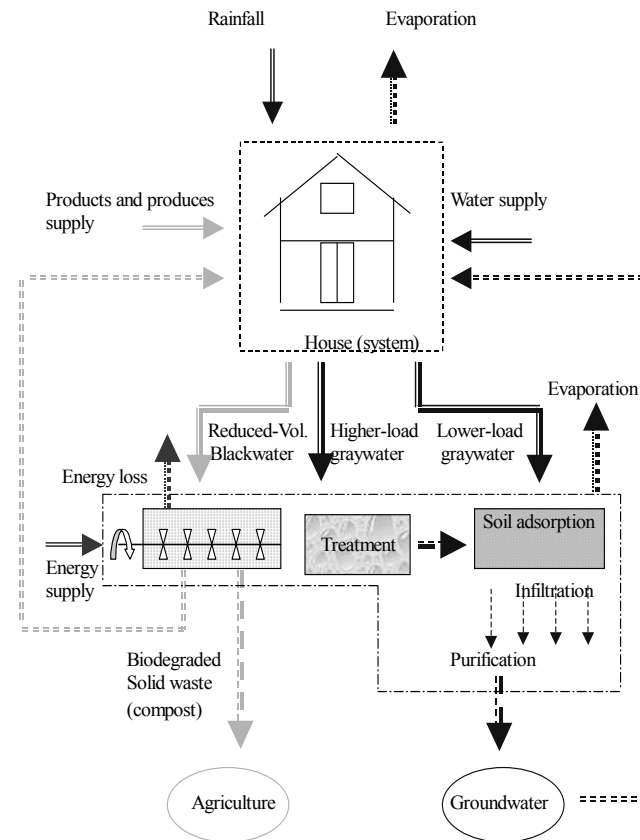


Figure 1: Hypothetical model for the onsite wastewater differentiable treatment system.

The essential and new concept in the OWDTS is to treat separately the three fractions of household wastewater. The importance of conceiving differentiable treatment for each fraction yields in the fact that:

- Blackwater is practically eliminated from the household wastewater effluent by using the bio-toilet, it means, approximately 31% of fresh water will be saved, 44% of organic load, 97% of $\text{NH}_3\text{-N}$, 80% of $\text{PO}_4\text{-P}$, and 77.4 % of TS will be eliminated from the household effluent.
- Higher-load graywater with a pollution concentration of 1079 to 1815 mg-COD/l represents 29% of household effluent and needs any conventional treatment process for reaching acceptable quality (Almeida *et al.*, 1999).
- Lower-load graywater could be treated by utilizing the natural capacity of soil microorganisms due to its pollution concentration was found to be 210 to 501 mg-COD/l (Almeida *et al.*, 1999).

Table 1: Contribution of each appliance for the daily total discharge volumes and pollutants loads (% of total volume or mass per 100 capita).

Appliance	Type of wastewater	Volume	COD	$\text{NH}_3\text{-N}$	$\text{NO}_3\text{-N}$	$\text{PO}_4\text{-P}$	TS
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WC	Blackwater	30.8 (31)	43.9 (44)	97.1 (97)	3.8 (4)	79.8 (80)	77.4 (77)
Kitchen sink	Higher-load graywater	13.0	23.2	0.3	38.0	9.4	10.1
Washing machine		16.2 (29)	22.3 (45)	1.2 (1.5)	7.6 (45)	4.3 (14)	4.0 (14)
Wash basin	Lower-load graywater	12.6	1.7	0.1	10.7	1.3	2.1
Bath		15.7	2.5	0.6	15.3	1.1	1.3
Shower		11.7 (40)	6.4 (11)	0.7 (1.4)	24.6 (51)	4.1 (6)	5.1 (9)
Total (per 100 capita per day)		10.23 m ³	11188 g	237.95 g	36.72 g	668 g	5610 g

Adapted from Almeida *et al.* (1999). Values in brackets are percentages per type of fraction of wastewater.

Benefits expected to get by implementing an OWDTS. The benefits of using an onsite wastewater differentiable treatment system (OWDTS) may be analyzed from the viewpoints of water and soil contamination prevention, conservation of resources, reduction of health risk for population, and economics. Such benefits may be the following:

- The sources of pathogens, mainly toilet wastes, are eliminated from the wastewater stream; therefore, the groundwater contamination risk is reduced considerably.
- The toilet wastes are converted into stable organic matter rich in nutrients, probably free of pathogens, that can directly be recycled into the household when a garden area is available or be disposed in external systems such as urban green areas or agricultural land. The organic matter and nutrients loops are closed.
- The reduction of blackwater volume is positive due to allows the saving and conservation of fresh water (probably drinking water) conventionally used in toilet flushing and the reduction of wastewater flow rate to be treated.
- Utilization of the natural capacity of soil organisms to biodegrade the lower-organic load graywater.
- Reduced volume of graywater (higher-load graywater) to be treated by conventional treatment processes, therefore, small size of treatment facilities, easier operation, and lower operation costs.
- Safety and healthy disposal of treated wastewater into the soil and probable reuse of groundwater for the household and urban consumption. The water loop is closed.
- Recovery of static and dynamic groundwater levels in urban zones where groundwater is an important source for water supply. This fact is important from two points of view, the pumping costs and the structural stability of soil and urban infrastructure.
- Integration of water, wastewater and household waste management.
- “Zero wastewater discharge” into the centralized sewer system.

BRIEF DESCRIPTION OF THE AEROBIC BIODEGRADATION OF TOILET WASTES USING SAWDUST AS A MATRIX

Aerobic biodegradation of toilet wastes by using sawdust as a matrix is an essential treatment process of the OWDTS. Bio-toilet is the name of a dry closet (DC) or composting toilet (CT). Bio-toilet is a non-water carriage toilet that uses natural biological decomposition to transform toilet wastes (feces, urine and toilet paper) into a relatively dry, nutrient-rich humus material called compost. Although, bio-toilet is commercially available and even under operation, no qualitative and quantitative data of the biodegradation processes (reaction kinetics) occurring in the sawdust matrix are available. This fact reveals the significance of conducting a research on this concern that contributes in the proper planning, design, installation, operation and maintenance of OWDTS, when the bio-toilet is used to eliminate blackwater and nutrients, especially nitrogen and phosphorous, from the household wastewater stream.

Physical and chemical properties of sawdust.- The benefits of using the sawdust matrix are derived from its inherent characteristics: high porosity, high void volume ratio, high water and air retention, high drainage, high bacterial tolerance, low apparent density, and biodegradability. The first four characteristics create an ideal environment for aerobic bacteria to thrive, decompose, and separate organic materials into carbon dioxide and water without odor generation (Terazawa, 1999).

Kinetics of aerobic biodegradation of toilet wastes using sawdust as a matrix.- Kinetics describes the rates at which phenomena (biodegradation) occur. There are four major factors influencing the rate of biodegradation.

- a) Microorganisms (number, type).
- b) Substrate quantity and bioavailability (composition, lignin content, particle size, etc.).
- c) Nutrients, macro (N, P, K, S) and micro (Mg, Co, etc.).
- d) Environmental conditions (moisture, porosity, temperature, oxygen, pH).

As known, heterotrophic organisms, mainly bacteria, biodegrade organic matter. Terazawa (1999) have found that in systems based on sawdust as a matrix (bio-toilet), bacteria are the microorganisms responsible of aerobic biodegradation. On the other hand, toilet wastes (mainly urine) are rich in nutrients, so that, nutrients availability is not a limiting factor for bacteria growth. Under those considerations, optimum substrate quantity and bioavailability and environmental conditions must be set in order to describe aerobic biodegradation kinetics. A research have been undertook in order to achieve the following objectives:

- a) Qualitative and quantitative description of processes' kinetics of the aerobic biodegradation of toilet wastes using sawdust as a matrix.
- b) Establishment of mathematical model to describe the kinetics of aerobic biodegradation of toilet wastes using sawdust as a matrix.
- c) Development of criteria for the proper design and operation of toilet wastes treatment systems by using sawdust as a matrix.

OVERVIEW OF POTENTIAL TREATMENT PROCESSES FOR HIGHER-LOAD GRAYWATER

Under the concept of OWDTs, higher-load graywater constitutes only 29% of household wastewater and 42% of total graywater. Unlike traditional OWTS, in OWDTs only 29% of total wastewater needs to be treated. This fact is very important because smaller, compact, more economic and easier operation treatment systems are allowed, essential characteristics that are looked for when a OWDTs is planned. Candidate technologies for higher-load graywater treatment must be robust to contamination from all likely sources.

Stephenson and Judd (2000) reported that bleach and bathroom cleaners were seen as the most frequently introduced contaminants of graywater, with mud animal and vegetable oil and food as secondary contaminants. Bleach was shown to be the most important pollutant, having a very low critical concentration and a high projected introduction frequency. Under the concept of higher-load graywater, those contaminants are mainly the constituents of such fraction. Due to the growing concern over salmonella and *E. coli* contamination from beef and poultry operations, candidate technologies for higher-load graywater treatment must be robust to contamination from all likely sources.

Recently, several researchers around the world have shown interest in graywater treatment, some of them applying technologies developed initially for wastewater. Technologies applied or developed range from simple systems for single house applications to very advanced treatment trains for large-scale reuse. Single house systems include two different stages, a coarse filtration stage and a disinfection process (Jefferson *et al.*, 2001). These systems present weaknesses such as low process performance and effectiveness, disinfectant by-products, regular maintenance requirement, training of householder to carry out maintenance and minimal economic benefits.

Physical systems such as depth filters and/or membranes have been developed because they produce a higher quality effluent than the single house systems, however, they suffer from maintenance, operational and economic constraints. In case of filters, backwashing is required to decompact and regenerate the media bed, and removal of top layer of sand. The key factor limiting the economic viability of membrane systems is the fouling of the membrane surface by pollutant species (Jefferson *et al.*, 2001).

Many natural systems exist for the treatment of graywater. Irrigation systems, washwater gardens, artificial wetlands and filtration technologies have been used successfully to treat graywater (Del Porto and Steinfeld, 2000); however, current tendencies are aimed at finding small-footprint treatment processes for in-building recycling of wastewater in large residential accommodation and office buildings.

Under above perspective, Stephenson and Judd (2000) carried out a study to investigate the feasibility of combining existing innovative technologies into a small-footprint biological treatment process for in-building recycling of wastewater in large buildings. They compared treatment performance and economic issues of enhanced biological methods, such as biological aerated filters (BAF) and membrane aerated bioreactors (MABR), and conventional (biomass separation) membrane bioreactors (MBR) such as submerged MBR and side MBR. They found that the submerged membrane bioreactor (subMBR) demonstrates a palpably better treatment performance and better economics over a range of operation scale appropriate to water reuse in large buildings. Despite this study was mainly focused on in-building recycling of wastewater in large buildings, regarding the characteristic of small-footprint treatment process, lower sludge generation and automated operation, MBR seems to be also a viable alternative to treat higher-load graywater; however, treatment performance and economic evaluation should be carried out.

A major barrier to the uptake of biological processes, especially on a smaller scale, is their susceptibility to toxic shock loads, such as the spiking of graywater sources by substances that are not traditional components of it, for example bleach (Jefferson *et al.*, 2001).

DESCRIPTION OF NATURAL SOIL TREATMENT SYSTEM (NSTS) FOR LOWER-LOAD GRAYWATER

Natural soil treatment systems for wastewater are not new, used of land-based natural treatment systems in the United States dates from the 1880s. As in Europe, these systems became relatively common as a first attempt to control water pollution. In the first half of the twentieth century, these systems were generally replaced either by in-plant treatment systems or by (1) managed farms where treated wastewater was used for crop production, (2) landscape irrigation sites, or (3) groundwater recharge sites. These newer land-treatment systems tended to predominate in the western United States, where the resource value of wastewater was an added advantage (Metcalf and Eddy, 1991). Land treatment processes include slow rate, overland flow and rapid infiltration. In addition to these three processes, land is also used for various onsite soil absorption systems designed to treat septic tank effluent (Reed S. *et al.*, 1995; Metcalf and Eddy, 1991). Among other natural and ecological systems, the gardening graywater irrigation, washwater garden and artificial wetlands can be mentioned (Del Porto and Steinfeld, 2000). Because these systems were initially developed for wastewater (black and graywater), they could be more viable when lower-load graywater is regarded.

Main pollutants of lower- load graywater are COD and nitrates whose sources are body soaps, shampoos, cleaners and others used in shower, washbasin and bath, see Table 1. Regarding the source of this graywater, it is not risky to suppose that lower-load graywater is practically free of pathogens. This assumption is very important because it means that subsurface direct disposal of lower-load graywater into the soil system is possible. This practice is not allowed by some state regulations in the USA and other countries around the world when total graywater is regarded. However, under the concept of lower-load graywater the subsurface direct disposal may be possible with very interesting implications. First, about 40% of household wastewater will be disposed into the soil without receiving any treatment; second, it is an economic practice; and third, it is supported by some of the environmental and health principles mentioned above.

Well known is the capacity of soil microorganisms to biodegrade organic matter under aerobic and/or anaerobic conditions. Garland *et al.* (2000) found that Igepon added to recirculating hydroponic systems was rapidly removed from solution (i.e., half life <1 hour) via microbially mediated degradation. In addition, surfactant loading increased total microbial abundance in the system. Igepon TC-42 (sodium N-coconut acid -N-methyl taurate) is a common surfactant of soaps and detergents. Regarding this capacity of microorganisms for degrading surfactants in solution, it is expected that soil microorganisms display the same capacity for reduction of COD and denitrification.

Despite above systems have been successful for managing and treating wastewater, when natural treatment and purification of lower-load graywater by the soil ambient is planned, the system should be evaluated regarding factors influencing the biodegradation kinetics:

- a) Soil microorganisms (number, type).
- b) Substrate quantity and bioavailability (graywater composition, microbial toxicity, phytotoxicity).
- c) Nutrients, macro (N, P, K, S) and micro (Mg, Co, etc.).

- d) Environmental conditions (moisture content, temperature, oxygen availability, pH, infiltration velocity, pluvial precipitation, vegetation type, evaporation/evapotranspiration, salt content, etc).

BRIEF DESCRIPTION OF CURRENT RESEARCH PERFORMANCES.

Evaluation of organic load influence on aerobic biodegradation of feces.- Organic load influence on aerobic biodegradation of feces by using sawdust as a matrix was evaluated. Batch tests for five different feces-sawdust ratios (F/S= 5, 10, 15, 20 and 25%, on dry basis) were performed at 55°C. Changes (reduction) in values of parameters such as chemical oxygen demand (COD), total solids (TS), volatile solids (VS), total nitrogen (T-N), ammonia (NH₃-N) and others were measured. In addition, oxygen utilization rate (OUR) by microorganisms during biodegradation was also monitored every 30 minutes.

Development of bio-kinetic model.- A bio-kinetic model was prepared and kinetic parameters were determined by respirometry, curve-fitting techniques and sensitivity analysis, and through the performance of batch tests; additionally, four different feces intermittent-addition tests were conducted for confirming the estimated parameters (Lopez *et al.*, 2000 a).

Characterization of feces.- An approach for characterizing organic matter of feces was developed based on physicochemical determinations and biological response during aerobic degradation. Batch tests for four different feces/sawdust ratios (F/S: 5, 10, 15 and 25%, on dry basis) were conducted at 55°C (Lopez *et al.*, 2000 b).

Temperature effect on aerobic biodegradation of feces.- Effect of temperature on aerobic biodegradation of feces was evaluated through the comparison of oxygen utilization rates (OUR) observed in batch tests performed under different temperatures, 20, 30, 40, 50, 60 and 70°C. Additionally, kinetic parameters were estimated for each temperature and the trend of them was analyzed.

Moisture content effect on aerobic biodegradation of feces.- Effect of moisture content on aerobic biodegradation of feces was evaluated through the comparison of oxygen utilization rates (OUR) observed in batch tests performed under different initial moisture contents, 55, 60, 65, 70, 75 and 80°C. Additionally, kinetic parameters were estimated for each temperature and the trend of them was analyzed.

Influence of temperature on pathogens decline.- Pathogens decline during the aerobic biodegradation of feces was evaluated through the performance of batch tests at different temperatures, 20, 30, 40, 50, and 60°C. Decline of total and fecal coliforms were used as indicator of pathogens decline.

Higher-load graywater treatment.- Based on 43 reports published in Japan from 1970 to 1990, contributions for daily graywater discharge and pollution load from various appliances such as kitchen sink, wash basin, bath, shower and washing machine, were determined. Additionally, size estimation of flow equalization tank and biological reactor for treatment of higher-load graywater was estimated regarding different combinations of graywater sources (Funamizu *et al.*, 2001).

CONCLUSIONS

- a) Regarding the actual tendencies towards ecological sanitation in recycling society and the pressure on the world's water resources, the OWDTS seems to be a reliable ecological sanitation alternative for treatment of domestic wastewater in developing countries.
- b) Aerobic biodegradation of toilet wastes by using sawdust as a matrix is an essential treatment process of the OWDTS. A research has been undertaken in order to describe the kinetics involved in those processes.
- c) Higher-load graywater treatment should be more deeply studied regarding factors such as flow rate variations, character and treatability of graywater contributions, treatment processes to be adopted, size of treatment facilities, disposal of treated effluents, operation and management, economic and sustainability. A study has been started attending those factors.

- d) Direct disposal of lower-load graywater into the soil and natural biodegradation by soil microorganisms needs to be deeply studied attending factors such as: soil microorganisms, substrate quantity and bio-availability (graywater character), nutrients availability and soil properties and environmental conditions.

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