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Environmental Protection
Agency

Wastewater Technology Fact Sheet

The Living Machine®

DESCRIPTION

The Living Machine® is an emerging wastewater treatment technology that utilizes a series of tanks, which support vegetation and a variety of other organisms. The Living Machine® was conceived by Dr. John Todd, President of the non-profit organization Ocean Arks International, and gets its name from the ecologically-based components that are incorporated within its treatment processes (microorganisms, protozoa, higher animals such as snails, and plants). The Living Machine® has sometimes been referred to as the "*Advanced Ecologically Engineered System*" or AEES. The Living Machine® is now designed and marketed by Living Machines, Inc. of Taos, New Mexico.

The Living Machine® is a second generation design. Dr. Todd developed the Living Machine™ design concept after working on a number of similar small pilot-scale facilities, now referred to as Solar Aquatics™ and marketed by Ecological Engineering Associates of Marion, Massachusetts.

The Living Machine® incorporates many of the same basic processes (e.g., sedimentation, filtration, clarification, adsorption, nitrification and denitrification, volatilization, and anaerobic and aerobic decomposition) that are used in conventional biological treatment systems. What makes the Living Machine® different from other systems is its use of plants and animals in its treatment process, and its unique aesthetic appearance. While these systems are aesthetic appealing, the extent to which the plants and animals contribute to the treatment process in current Living Machine® designs is still being verified (U.S. EPA, 2001). In temperate climates, the process is typically housed within a large greenhouse, which protects the process from colder temperatures.

Source: U.S. EPA., 2001.

FIGURE 1 THE OPEN AEROBIC TANKS OF THE LIVING MACHINE® IN SOUTH BURLINGTON, VT

Living Machines, Inc. describes the Living Machine® as being a wastewater treatment system that:

- Is capable of achieving tertiary treatment;
- Costs less to operate than conventional systems when used to achieve a tertiary level of treatment; and
- Doesn't typically require chemicals that are harmful to the environment" as a part of its treatment process (Living Machines, Inc., 2001).

Several federally-funded Living Machine® demonstration systems have been constructed, the largest of which handled design flows of up to 80,000 gpd. As configured for these demonstrations, these systems treated municipal wastewaters at various strengths, and reliably produced effluents with five-day biochemical oxygen demand (BOD$_5$), total suspended solids (TSS), and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L (U.S. EPA, 2001 and see Table 1). With regard to phosphorus removal, the Living Machine® process is capable of about 50 percent removal with influents within the 5-11 mg/L range (U.S. EPA, 2001). In addition to the demonstration projects, the Living Machine® technology is being used by a variety of municipal and industrial clients, where similar performance has been reported.

Treatment Process

A typical Living Machine® comprises six principle treatment components, after influent screening. In process order (see Figure 1), these are (1) an anaerobic reactor, (2) an anoxic tank, (3) a closed aerobic reactor, (4) aerobic reactors, (5) a clarifier, and (6) "ecological fluidized beds" (EFBs). While the open aerobic reactors and EFBs are found in almost all Living Machines®, the other components are not always utilized in the treatment process. The specific components used are selected by the designers depending upon the characteristics of the wastewater to be treated and the treatment objectives. Sometimes additional process components may be added if considered necessary by the designers. For example, the demonstration system in Frederick, Maryland utilized a "Final Clarifier" and a high-rate subsurface flow (SF) wetland as the last two components of its treatment train.

Anaerobic Reactor (Step 1)

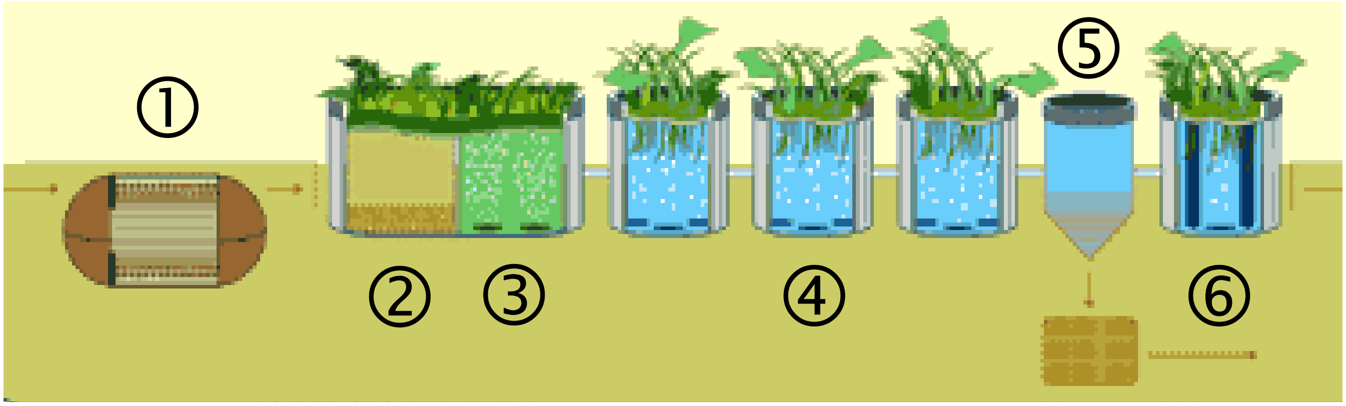
When it is employed, the anaerobic reactor serves as the initial step of the process. The reactor is similar in appearance and operation to a septic tank, and it is usually covered and buried below grade. The main purpose of the anaerobic reactor is to reduce the concentrations of BOD_5 and solids in the wastewater prior to treatment by the other components of the process. When necessary, gases are passed through an activated carbon filter to control odor.

Raw influent enters the reactor, which acts as a primary sedimentation basin. Some of the anaerobic reactors used have an initial sludge blanket zone, followed by a second zone for clarification. Additionally, strips of plastic mesh netting are sometimes used in the clarification zone to assist with the trapping and settling of solids, and to provide surface area for the colonization of anaerobic bacteria, which help to digest the solids. Sludge is typically removed periodically via perforated pipes on the bottom of the reactor, and wasted to a reed bed or other biosolids treatment processes. Gasses produced are passed through an activated carbon filter or biofilter for odor control.

Anoxic Reactor (Step 2)

The anoxic reactor is mixed and has controlled aeration to prevent anaerobic conditions, and to encourage floc-forming and denitrifying microorganisms. The primary purpose of the anoxic reactor is to promote growth of floc-forming microorganisms, which will remove a significant portion of the incoming BOD_5.

Mixing is accomplished through aeration by a coarse bubble diffuser. These diffusers are typically operated so that dissolved oxygen is maintained



Source: Living Machines Inc., 2001.

FIGURE 1 THE COMPONENTS OF THE LIVING MACHINE®: (1) ANAEROBIC REACTOR, (2) ANOXIC REACTOR, (3) CLOSED AEROBIC REACTOR, (4) OPEN AEROBIC REACTORS, (5) CLARIFIER, AND (6) "ECOLOGICAL FLUID BED" below 0.4 mg/L. The space over the reactor is vented through an odor control device, which is usually a planted biofilter. Additionally, an attached growth medium can be placed in the compartment to facilitate growth of bacteria and microorganisms.

Settled biosolids from the clarifier (Step 5), and nitrified process water from the final open aerobic reactor (Step 4) are recycled back into this reactor. The purpose of these recycles is to provide sufficient carbon sources to the anoxic reactor to support denitrification without using supplemental chemicals, such as methanol.

Closed Aerobic Reactor (Step 3)

The purpose of the closed aerobic reactor is to reduce the dissolved wastewater BOD_5 to low levels, to remove further odorous gases, and to stimulate nitrification.

Aeration and mixing in this reactor are provided by fine bubble diffusers. Odor control is again achieved by using a planted biofilter. This biofilter typically sits directly over the reactor and is planted with vegetation intended to control moisture levels in the filter material.

Open Aerobic Reactors (Step 4)

Next in the process train are the open aerobic reactors, or aerated tanks. They are similar to the closed aerobic reactor in design and mechanics (i.e., aeration is provided by fine bubble diffusers); however, instead of being covered with a biofilter, the surfaces of these reactors are covered with vegetation supported by racks. These plants serve to provide surface area for microbial growth, perform nutrient uptake, and can serve as a habitat for beneficial insects and microorganisms. To what extent the plants enhance the performance treatment process in the Living Machine® is still being verified (U.S. EPA, 2001). However, with the variety of vegetation present in these reactors, these units (along with the Ecological Fluidized Beds - Step 6) set the Living Machine® apart from other treatment systems in terms of their unique appearance and aesthetic appeal.

The aerobic reactors are designed to reduce BOD_5 to better than secondary levels and to complete the process of nitrification. The size and number of these reactors used in a Living Machine® design are determined by influent characteristics, effluent requirements, flow conditions, and the design water and air temperatures.

Clarifier (Step 5)

The clarifier is basically a settling tank that allows remaining solids to separate from the treated wastewater. The settled solids are pumped back to the closed aerobic reactor (Step 3), or they are transferred to a holding tank, and then removed for disposal. The surface of the clarifier is often covered with duckweed, which prevents algae from growing in the reactor.

Ecological Fluidized Beds (Step 6)

The final step in the typical Living Machine® process are the "ecological fluidized beds" (EFBs). These are polishing filters that perform final treatment of the wastewater, and one to three are used in series to reduce BOD_5, TSS and nutrients meet final effluent requirements.

An EFB consists of both an inner and outer tank. The inner tank contains an attached growth medium, such as crushed rock, lava rock, or shaped plastic pieces. The wastewater flows into the EFB in the annular space between the inner and outer tanks and is raised by air lift pipes to the top of the inner ring that contains the media. The bottom of the inner tank is not sealed, so the wastewater percolates through the gravel media and returns to the outer annular space, from where it is again moved back to the top of the gravel bed. The air lifts also serve to aerate the water and maintain aerobic conditions.

The unit serves as a fixed bed, downflow, granular media filter and separates particulate matter from the water. Additionally, the microorganisms that occupy the granular media surfaces provide any final nitrification reactions.

As sludge collects on the EFB, it reduces its ability to filter. This would eventually clog the bed completely. Therefore, additional aeration diffusers beneath the gravel bed are periodically turned on to create an upflow airlift, reversing the flow direction. This aeration is intended to "fluidize" the bed and release the trapped sludge (hence the name of this unit). This sludge is washed over and accumulated at the bottom of the outer annular space where it can be collected manually, and wasted along with the biosolids from the anaerobic reactor. Consequently, the name "ecological fluidized bed" is somewhat misleading for this unit since, in its treatment mode, it acts like a typical, conventional, downflow coarse media contact filter unit. Only during backwash cleaning does the bed become partially fluidized.

After this last step, the wastewater should be suitable for discharge to surface waters or a subsurface disposal system, or reused for landscape irrigation, toilet flushing, vehicle washing, etc. (Living Machines, Inc., 2001).

APPLICABILITY

The Living Machine® is well suited for treating both municipal and some industrial wastewaters. As with most treatment systems using plants, it can require a larger footprint than more conventional systems, and its requirement for a greenhouse in more temperate climates can impact costs. However, its unique and aesthetically pleasing appearance make it an ideal system in areas that oppose traditional treatment operations based on aesthetics (i.e., smell and appearance). The designers also stress the educational benefits of the Living Machine® (http://www.livingmachines.com/htm/planet2.htm) in raising awareness of wastewater treatment methods and benefits.

ADVANTAGES/DISADVANTAGES

Advantages

- Capable of treating wastewaters to BOD_5, TSS, and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L.

- Offers a unique, aesthetically pleasing environment for treating and recycling wastewater. This may be helpful when attempting to locate the treatment system in areas where the public opposes traditional wastewater treatment operations for aesthetic reasons.

Disadvantages

- The Living Machine® has only been shown to remove about 50 percent of influent phosphorous (with influents in the range of 5-11 mg/L). The removed phosphorus appears to be primarily associated with the incoming solids.

- The process requires a greenhouse for reliable operation in the cold weather of more temperate climates, adding to system costs.

DESIGN CRITERIA

Every Living Machine® system is designed by Living Machines, Inc. based upon the expected wastewater volume and content, as well as the treatment requirements and local climate. Once these factors are known, the designers then determine whether a greenhouse is necessary, what types of reactors are needed, how many of each type of reactor are required, and what capacity is required to achieve the suitable residence times.

PERFORMANCE

The Living Machine® has reliably achieved treatment goals of BOD_5, TSS, and Total Nitrogen $\leq$ 10 mg/L, Nitrate $\leq$ 5 mg/L, and Ammonia $\leq$ 1 mg/L. Table 1 shows the results of independent evaluations of two demonstration systems. The Living Machine® demonstration project in Frederick, Maryland was designed to treat 40,000 gpd of screened and degritted wastewater. It employed a single anaerobic reactor for primary solids digestion, then three parallel treatment trains, each comprised of two open aerobic reactors, a clarifier, three "ecological fluidized beds," a final clarifier, and a small, high-rate subsurface flow wetland. The demonstration project located in South Burlington, Vermont was designed to treat 80,000 gpd of screened and degritted wastewater,

TABLE 1 PERFORMANCE OF THE FREDERICK AND BURLINGTON LIVING MACHINES®

Parameter	FREDERICK				BURLINGTON			
	Influent mg/L	GH Influent mg/L[a]	Effluent mg/L	% Removal	Influent mg/L	Effluent mg/L	% Removal	Effluent Goal
BOD_5	230	156	4	97	227	5.9	97	<10
COD	944	378	21	94	556	35.9	94	--
TSS	381	70	2	97	213	5.3	98	<10
NH_3	-	22	1.2	94	16.3	0.4	98	<1
NO_3	-	20.8	10	52	15.9[b]	4.9	69	<5
TN (total nitrogen)	-	44	11	75	29.3	5.6	81	<10
TP (total phos-phorus)	11	7.7	6	45	6.0	2.0	67	<3

a Effluent from the anaerobic reactor at Frederick into the reactors contained within the greenhouse.
b Assumes that all removed ammonia is converted to nitrate.

Source: U.S. EPA, 2001.

and employed five open aerobic reactors (though one of these was later converted to an anoxic reactor), a clarifier, and three "ecological fluidized beds."

In these instances, the Living Machine® was capable of BOD_5 and TSS removal in excess of 95 percent. While the Frederick system did not consistently achieve its goal of < 5 mg/L for Nitrate, the Burlington Living Machine® did. The Living Machine® reliably demonstrated about 50 percent removal of Total Phosphorous (TP), although the Burlington system had a low influent TP concentration (U.S. EPA, 2001).

While the Frederick Living Machine® achieved quite good coliform removal (< 200 MPN/100mL), the Burlington system's effluent was above 1,000 MPN/100mL. Consequently, disinfection may be required as an additional step depending upon system configuration and effluent requirements.

OPERATION AND MAINTENANCE

Routine Activities

The routine operation and maintenance (O&M) requirements for Living Machines® are similar to the requirements for a conventional wastewater treatment plant, with a few additional requirements. These additional requirements include cleaning the inlet/outlet structure; cleaning the screen and tank; removing and disposing sludge; and maintaining and repairing machinery. Other requirements are vegetation management, including routine harvesting to promote plant growth, and removal of accumulated plant litter. Additionally, it may be necessary to manage fish and snail populations, and control mosquitoes and flies (if applicable).

Residuals Management

The Living Machine® produces residuals comparable in quantity to conventional treatment systems. However, some of these residuals are biosolids, while others are in the form of plant

TABLE 2 PRESENT WORTH COMPARISON OF “LIVING MACHINES®” AND CONVENTIONAL SYSTEMS

Process	40,000 gpd	80,000 gpd	1 million gpd
“Living Machine” with greenhouse	$1,077,777[1]	$1,710,280[1]	$10,457,542[2]
“Living Machine” without greenhouse	$985,391	$1,570,246	$9,232,257
Conventional System	$1,207,036[1]	$1,903,751[1]	$8,579,978[2]

(1) Cost difference is less than 20 percent
(2) Cost difference is greater than 20 percent

Source: U.S. EPA, 2001.

material. Analyses at the Frederick demonstration system showed that plant residuals could be composted and used for many agricultural or horticultural purposes. The biosolids would likely require stabilization and treatment to reduce pathogens and indicator organisms before they would meet Part 503 limits for sewage sludge (U.S. EPA, 2001).

COSTS

Since the Living Machine® is designed, marketed and trademarked by Living Machines, Inc., precise cost data are proprietary. However, a cost comparison with “conventional” treatment systems was performed as a part of an independent U.S. EPA evaluation of the Living Machines® (U.S. EPA, 2001). Table 2 summarizes the results of this cost comparison.

This analysis concluded that Living Machines® are typically cost competitive with more conventional wastewater treatment systems at flow volumes up to 1,000,000 gpd, if they are located in a warm climate where a greenhouse is not necessary. However, if the climate cannot support the plants year-round and a greenhouse must be constructed, construction costs will increase. Addition of a greenhouse structure makes the Living Machine® cost competitive with more conventional systems up to flow rates of around 600,000 gpd.

REFERENCES

Other Related Fact Sheets

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owm/mtb/mtbfact.htm

1. Living Machines, Inc., 2001. Web Site: http://www.livingmachines.com/

2. Massachusetts Foundation for Excellence in Marine and Polymer Sciences, Inc., Boston, MA, Ocean Arks International, Living Technologies, Inc., 1997. *Advanced Ecologically Engineered System, South Burlington, Vermont*.

3. U.S. EPA, 2001. *The “Living Machine” Wastewater Treatment Technology: An Evaluation of Performance and System Cost*. EPA 832-R-01-004.

ADDITIONAL INFORMATION

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