

Energy Efficient ReCip® Decentralized Wastewater Treatment Systems

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ABSTRACT

This paper provides a brief introduction to wastewater treatment; centralized and decentralized, followed by detailed information regarding the development and deployment of ReCip®, energy efficient decentralized wastewater treatment system. ReCip® is a robust and scalable treatment technology that has great potential for treating domestic, industrial and agricultural wastewater. Markets include many diverse applications both in the United States and internationally. The technology has been used to treat sanitary wastewater, acid mine drainage, CAFO wastewater (concentrated animal feeding operations), aquaculture wastewater, and food processing wastewater. ReCip® has also been used to remove explosives and nutrients from contaminated ground water, and to remove deicing compounds (ethylene glycol), from runoff at a commercial airport. ReCip® systems can be operated using gravel-only substrate, or augmented with various aquatic and terrestrial plants. Because it is an aerobic subsurface technology, there are no odor or mosquito vector problems. Pilot-scale ReCip® systems have been operated with UV lights to remove up to 99.9% of wastewater pathogens. The patented ReCip® technology is being marketed nationally and internationally via licensing and confidentiality agreements respectively.

1 INTRODUCTION

We are living in precarious times due to massive global environmental problems and a deep worldwide recession. And yet the world population continues to grow every day, putting greater stress on capital, energy and finite resources such as freshwater. It has been stated that “the failure to provide safe drinking water and adequate sanitation services to all people is perhaps the greatest developmental failure of the twentieth century” [1]. According to the World Bank, “The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes”

If we are to make significant progress in addressing water and wastewater issues, it will be necessary to move forward with the development and deployment of new technologies that are innovative, energy efficient, ecologically sustainable and cost effective. In the realm of

wastewater treatment, there are two main technologies defined by scale; centralized and decentralized.

1.1 Centralized Wastewater Treatment

Centralized wastewater treatment systems are typically large, complex, and highly engineered and are most appropriate for large cities where wastewater flows are in the range of millions to hundreds of millions of gallons per day. These systems require highly trained operators and extensive large-pipe sewerage and lift stations to convey the wastewater to the centralized treatment facility. These highly engineered systems tend to be energy intensive and costly to build, operate and maintain.

While these systems provide relatively rapid treatment, the treated discharge often contains low levels of residual nutrients and a significant number of recalcitrant compounds including pharmaceuticals and industrial by-products. Following treatment, the water is disinfected, usually via chlorination-dechlorination, and discharged to receiving streams, lakes and ocean out-falls. Following decades of such practice, large aquatic ecosystems such as the Chesapeake Bay, the Great Lakes, and the Gulf of Mexico have been damaged due to eutrophication, pollution, and chronic oxygen depletions. These “dead zones” are now common throughout the world and have damaged 95,000 square miles [2]. It should be noted that industrial agriculture has also been responsible for polluting waterways with nutrients, herbicides and pesticides.

The infrastructure of many of these large sewerage systems is aging and in need have repair. Following is a recent EPA summary assessment from their web page: “America’s drinking and wastewater infrastructure is aging and the costs and environmental risks due to failure are sobering. Some 240,000 drinking water mains break each year costing billions in lost water. Wastewater collection systems experience thousands of sanitary sewer overflows annually, discharging billions of gallons of untreated wastewater into the environment. A recent EPA analysis of the potential funding gap in U.S. infrastructure needs by the year 2020, projected that if operation, maintenance, and capital investment remain at current levels, the potential funding shortage for drinking water and wastewater infrastructure could exceed \$500 billion.

1.2 Decentralized Wastewater Treatment

In their book “Small and Decentralized Wastewater Management Systems”, Crites and Tchobanoglous [3],

provided this message “At one time, it was envisioned that centralized sewerage facilities would be available for most citizens. However, it is now recognized that complete sewerage may never be possible or desirable due to geographical and economic reasons. Given the fact that complete sewerage is unlikely for many residents, it is clear that decentralized wastewater management is of great importance to the future management of the environment”.

Decentralized and on-site wastewater treatment systems and ultra-violet (U.V.) disinfection, will be increasingly important technologies in the wastewater treatment industry throughout the world. In the recent past, most decentralized systems were designed primarily for wastewater disposal, with little regard for treatment or environmental impact. However today, there are more stringent discharge standards and an increasing worldwide demand for non-polluted freshwater. Thus there is an imperative for developing and deploying low-cost decentralized treatment systems that are protective of the environment and public health, while providing options for water reuse [4].

As compared to centralized systems, decentralized systems, such as constructed wetlands, are less complex and more energy efficient, economical and environmentally sustainable. These systems are scalable and economical over the range of 100 to 1 million gallons/day. Decentralized technologies are appropriate for individual homes, small businesses, towns, rural villages, new housing developments, schools, industrial parks, and confined livestock facilities. With respect to energy use, some decentralized technologies use from 10 to 100 times less energy than conventional technologies such as activated sludge [5].

Total retention time in decentralized systems is highly variable and is dependent on climatic region, type of system, and regulatory mandates [6]. Longer retention times require more land and expense but provide opportunities to treat the wastewater to standards required for reuse options. Decentralized systems typically treat and dispose of the treated wastewater within the development limits, and thus provide opportunities for water reuse and conservation. On-site disposal, such as leaching fields or irrigation also provides additional treatment as the water percolates through the soil profile. This is critically important for removal of residual phosphorus, another fertilizer nutrient that can cause serious eutrophication in water ways.

2.0 RECIPROCATING WATER TECHNOLOGIES

ReCiprocating Water Technologies, ReCip® is an award winning decentralized treatment system (EPA Environmental Merit Award, 2000), that was developed and refined by scientists at the Tennessee Valley Authority in Muscle Shoals, AL. ReCip® is a simple, versatile, robust, and economical technology that can be deployed rapidly

using local materials and local labor. To date ReCip® has been used to treat sanitary wastewater, explosives-contaminated groundwater, food processing wastewater, aquaculture waste water, airport deicer, high strength wastewater from confined livestock operations (including high density aquaculture) and simulated acid mine drainage [7,8,9]

2.1 ReCip® Treatment Environments

Recip® includes patented improvements in the design and operation of paired subsurface-flow constructed wetlands such that paired gravel-filled cells are filled and drained on a frequent and recurrent basis (U.S. Patent 5,863,433 [10]). The fill and drain pumping process is controlled by digital programmable timers. In properly designed and operated systems, the recurrent reciprocation process promotes development of sequential aerobic, anoxic and anaerobic environments. Recurrent exposure of wastewater to these distinct environments is essential for removal of mixed metals, nitrogen (ammonia and nitrate), and many natural and man-made recalcitrant compounds [11].

2.1 ReCip® Treatment Operations

During the drain cycle, micron-thin water films surrounding plant roots and substrate biofilms are exposed to atmospheric oxygen. Diffusion of oxygen through such thin films is nearly instantaneous, and as such there is sufficient oxygen for aerobic processes such as respiration and nitrification. This is critically important for high strength wastewaters such as those produced at confined animal feeding operations (Figure 1). Under conditions of high ammonium-N concentrations (400-600 mg/L), ReCip® systems have removed up to 200 lbs/acre/day via biological nitrification and denitrification [12]. This ability to remove tons of nitrogen on an annual basis will be an economically important factor with respect to impending legislation related to total daily maximum loads (TMDL's) and nutrient trading. The drain cycle also allows supersaturated metabolic gases, such as carbon dioxide (CO₂), to pass from biofilms into the atmosphere. Off-gassing of CO₂ helps maintain near neutral pH, and promotes abiotic precipitation of calcite and phosphorus compounds.

During the subsequent fill cycle microbial biofilms are bathed in anoxic water, where reducing conditions are near optimum for microbial-induced reduction of sulfate and nitrate. Sulfate reduction is required for removing many metals as metal sulfides [13]. Because the contiguous treatment environments are alternated as often as six to twelve times daily, the system is in perpetual flux and no particular microbial consortia can predominate. This promotes development of a stable, high-diversity microbial biomass which is advantageous to treatment of complex mixed-wastewater



Figure 1. Aerial view of commercial-scale ReCip® demonstration for treating high strength wastewater from a confined swine operation. Based on independent studies performed by North Carolina State University: (http://www.cals.ncsu.edu/waste_mgmt/smithfield_projects/phaseIreport04/phaseIreport.htm), this two-cell system was removing total nitrogen at an average rate approaching 200 pounds per acre per day.

Reciprocation also provides frequent aeration of the root zone, and therefore it is possible to culture a wide variety of aquatic, terrestrial and ornamental plants (Figure 2), This is an important feature, both from an aesthetic and treatment standpoint as some plants have unique qualities for extracting pollutants from contaminated water, soil or sediments [14]. This “phytoremediation” process has been used successfully to contain, degrade or eliminate nutrients, metals, pesticides, explosives, solvents and even crude oil.



Figure 2. Small ReCip® “water garden” designed to treat up to 300 gal. per day (appropriate for a single

household). The two treatment cells were planted with black elephant ears, miniature lotus, miniature cattails and various day lilies. The exposed PVC plumbing was installed for experimental monitoring processes.

2.2 ReCip® Energy Use and Efficiency

Energy efficient axial flow pumps are used intermittently in medium- to large-scale reciprocating systems as they are ideally suited for moving large volumes of water between contiguous cells. Axial flow pumps are specially designed and adapted to provide maximum flows for applications where the water only needs to be “lifted” a few feet. The total electrical costs for operating two 0.75 horsepower axial-flow pumps for treating up to 40,000 gal/day of sanitary wastewater is approximately \$1.20/day. This assumes 6 hours of run time/pump /day @ \$0.075/kwh. This compares to \$34/day for a comparable activated sludge plant using fine bubble aeration [5]. Thus, the energy carbon footprint for ReCip® is 28 times less than for the activated sludge process.

2.3 ReCip® Construction Costs

Most of the materials, equipment and supplies required for constructing and operating ReCip systems are “off the shelf” and readily available from local contractors and vendors, or internet companies. These include heavy equipment for excavation and grading, appropriate rubber or HDPE liners, graded gravel substrates, programmable digital timers, water level control devices, corrugated plastic pipes for underdrains and pump chambers, axial flow pumps, electrical supplies and control panel, and PVC pipe and fittings. Construction costs can range from \$3 to \$30 per design gallon. The wide range in construction costs is due to suitability of the site, regional engineering and contractor fees, the cost and availability of graded gravel, and the proximity of gravel to the construction site (transportation of gravel can be a major cost). If the construction site has deep soils and is easy to excavate, then low-cost in-ground systems can be constructed. However, in areas with shallow bedrock, the system may require construction of above-ground cement block or expensive reinforced cement cells.

ReCip systems are relatively easy to install and with proper oversight can be installed rapidly. A 40,000 gal/day sanitary wastewater system was installed at an industrial park within 60 days (Figure 3). The system included a two cell ReCip®, two 20,000 gal clarifiers in tandem and an extensive leaching field.

Because ReCip® is a relatively inexpensive decentralized technology, it will also have a significant role in international development. Local labor and materials can be used to construct and operate these systems which also control costs and help the local economy. In 2007, a 5000 gal/day system was installed at a diving resort on



Figure 3. Commercial 40,000 gal/day sanitary wastewater ReCip® system installed at the Barton Riverfront Industrial Park, Barton, Alabama. The black upright cylinders are pump chambers to house axial flow pumps. This system is operated as a gravel-only system with no plants.

Curacao, a desert Isle (Figure 4). Instead of using costly gravel substrate, the contractor used local coral gravel and sand which provided significant savings.

Clear and odor free effluent from the water garden is used for landscape irrigation with residual water sold to water supply vendors (Figure xxx).



Figure 4. Four-cell ReCip® "Water Garden" installed at Sunset Beach Diving Resort on the desert island Curacao. The system treats up to 5000 gallons of clarified wastewater each day. The clear and odor free wastewater is used for irrigating landscape plants, while excess water is sold to water vendors who resell the treated wastewater for irrigation

TVA and the American Public Power Association recently completed research to evaluate the integration of low-wattage ultraviolet light technology (UV) into a pilot-scale ReCip® system. ReCip's fill and drain operation

enabled multiple exposures (6-12 times/day), of wastewater pathogens to low wattage UV lights. With multiple exposures, the integrated system provided 99.9% removal of wastewater pathogens with no measureable impact on biological wastewater treatment function [7]. Treated wastewater exiting the UV-ReCip® system was clear, odor free and with very low levels of nutrients, pathogens and other pollutants. As a result, the treated wastewater can potentially be reused for flush water, irrigation, and ultimately to recharge groundwater supplies.

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