Soil as a wastewater treatment system: historical development

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Abstract “Land treatment” refers to the application of wastewater to the soil to achieve treatment and to meet irrigation needs of the vegetation. Application of wastewater to the land was the first practice used to protect public health and control environmental pollution. This technology has gone through different stages of development with time but it was not until 1840s when the basic principles of this technology started to establish. The use of land treatment for wastewater treatment declined after the development of conventional treatment plants but a renewed interest occurred after the passage of Clean Water Act and especially, during the last two decades. Currently, its application has been expanded in the management of various types of wastewaters including dairy, meat, industrial effluents as well as and polluted water sources. It is recognized as the ideal technology for rural communities, clusters of homes and small industrial units due to low energy demands and low operation and maintenance costs. Furthermore, in conjunction with biomass production can contribute in the control of climate change. A brief historical overview along with an introduction to the fundamental processes the current trends and the future prospects are provided in this section.

Keywords History of land treatment; sanitation; wastewater management

Introduction

Land treatment is defined as “the controlled application of partially treated wastewater onto land to achieve treatment and disposal goals in a cost-effective manner” (Crites et al., 2000). Land application is the oldest practice used to manage wastewater and control environmental pollution. Historical evidence of wastewater spreading to the soil for crop irrigation and sanitation purposes goes back to the ancient cities and palaces of Minoan Civilization (Angelakis and Spyridakis, 1996; Angelakis et al., 2005). With the progress of time land treatment has gone through different stages of development but the basic principles regarding the planning, operation and management practices were developed after 1850 when the “sewage farms” were expanded in Europe and USA in an effort to control pollution and protect public health (U.S. EPA, 1979).

The development of conventional wastewater treatment technologies in the turn of 19th century resulted in a decline of land treatment systems (Reed et al., 1995), but the interest was renewed after the passage of Clean Water Act in 1972 and particularly the last two decades. This is mainly due to the low construction, operation and maintenance costs, making this technology suitable for small communities or decentralized clusters of homes, institutions and isolated industrial units (Crites and Tchobanoglous, 1998; Angelakis, 2001). Different types of land treatment systems were developed through the passage of time depending on the rate of applied hydraulic load, the presence or absence of vegetation, the needs for preapplication treatment and the intended level of treatment. These include: slow rate systems (SR): these systems utilize soil matrix for treatment and the applied load is based on vegetation water requirements; overland flow (OF): they utilize soil surface and vegetation for treatment and the treated wastewater is collected as
runoff; and rapid infiltration (RI); the major difference from SR systems is the lack of vegetation and the higher application rates (Reed et al., 1995).

Nowadays, land treatment is recognized as an alternative or supplement to conventional wastewater treatment plants that can be both environmentally sound and economically viable. Land treatment systems have been currently expanded for the treatment of various types of effluents including landfill leachates, dairy effluents, meat processing wastewater, olive oil mill wastewater, agricultural drainage, and contaminated groundwater (Paranychianakis et al., 2006 and references there in). In addition, the direction of land treatment systems toward biomass production and bioenergy observed in recent years may contribute to climate change mitigation. Currently, the scientific interest focuses on the adoption of appropriate operation and management strategies that could alleviate the potential adverse environmental impacts, understanding the cycling of nutrients and their removal, the fate of pathogenic organisms and the factors affecting their survival, and the fate of toxic organic compounds.

In this study a brief overview of historical evolution of land treatment concept is discussed with emphasis on the most important technological developments and on the sanitation requirements. Furthermore, the current trends and the future prospects of land treatment concept are presented in terms of management of wastewater and other polluted water sources.

Chronological development of land treatment systems

The existing literature suggests that some ancient civilizations practiced land treatment for irrigation and sanitation purposes, but the development and the expansion of this practice for wastewater management occurred mainly in three distinct periods beginning in 1840. The first period took place from 1840 to 1905, when the basic principles were developed and the spreading of this technology occurred. The second period lasted until 1972 when the Clean Water Act was enacted and characterized by a sharp drop in the development of these systems. Finally, the third period from 1972 until today, a renewed interest has been observed for the adoption of land treatment systems to treat various types of effluents and polluted waters.

Land treatment systems in the ancient times

In the early days of the hunter-gatherer, bones and animal waste were left on the ground to enrich the soil. In that period, everything that could be was repaired and reused. However, as time progressed, and people began to live in communities, significant amounts of wastes and wastewater were produced in many ancient cities. Findings from archaeological sites in Knossos, Cyclades, Athens and the mainland reveal that ancient Greeks were aware of the basic hydraulic principles which led to the development of innovative technological achievements for water and wastewater capture, conveyance, storage and treatment (Cahill, 2003; Koutsoyiannis and Angelakis, 2004; Angelakis et al., 2005). The most impressive water-related technological achievements occurred during the Minoan civilization (since 3500 B.C). The severe water shortage which was experienced by the ancient Minoans probably led to these developments, the recognition of water value and the need for efficient exploitation of all the available water sources. During that period elaborate sewage and drainage systems were constructed to support both the functional needs of palaces and cities and the requirements of sanitation (Figure 1). The “stabilization and sedimentation tanks” found in the palace of Phaistos, Tyllisos, and Agia Triada villa (Figure 2) also indicate that ancient Minoans were aware of the need of treatment to ensure water of appropriate quality. The use of stormwater for irrigation as well as the beneficial effects of mixing stormwater with wastewater seems to
be known to ancient Minoans. There are indications of using wastewater and stormwater from the central sewerage system south west of Phaistos in the Messara valley (Figure 3). Thus there is substantial historical evidence suggesting that ancient Minoans were among the first to have used wastewater for irrigation of agricultural land from 3500 BC. Doxiadis (1973) reported the existence of sewers through which wastewater was transferred to land treatment sites. Furthermore, from 2600 BC, many ancient Greek civilizations in Athens, Dion, Cyprus, Katerini and Sparti, practised wastewater irrigation of agricultural crops to ensure sanitation and benefits of the nutrients contained in wastewater for increasing yield (Angelakis et al., 2005).

In 2000 BC, composting is known to have been a part of life in China. During the European Bronze Age bronze waste recovery systems were in place. By 500 BC, in Athens, drainage from storm water and sewage may have run outside the city by channels to irrigate crops, since they had recognized the nutrient value of the sewage (Crouch, 1993). In Athens, also the first municipal landfill site had been opened outside the city (http://en.wikipedia.org/wiki/History_of_waste_management). From 200 BC to 100 AC, olive mill liquid waste, called amurca, was considered valuable in agriculture. Several ancient authors described that amurca could be used as a fertilizer for wheat (Varro, I, 57, 2), olive trees (Cato XCIII), vines and fruit trees (Columella, XI, 2; “Geoponica”, II, 10). Also, amurca was recommended as a liquid for moisturizing beans before sowing to make them grow larger (Virgil, Georgics, I, 95; Pliny the Elder, XVII, 45). The ancients were also aware of the undesirable effects of direct application of amurca into the soil, and for that reason they applied controlled release of that waste (Varro, I, 55, 7). In the Bible two references are found for wastewater application to the land (Deuteronomy xxiii, 13 and Judges iii, 20). In following years, however, until 12th century the practice of land treatment disappeared and the concept of sanitation was totally lost. A new concern for health and water issues was shown during the Renaissance when cesspools were used as sedimentation tanks and liquid soil infiltration was practiced.
The first period of land treatment development: 1840–1905

In the more recent history, wastewater effluents were being used in Bunzlau, Germany, for beneficial crop production beginning in 1531 (Gerhard, 1909). In 1650 the “Crargentinny Meadows” project was developed in Edinburgh, Scotland, where the city’s sewage was directed to adjacent fields for crop irrigation (Stanbridge, 1976). This project had a significant impact on the later expansion of land treatment as it clearly indicated the beneficial effects of wastewater application on crop yield. The epidemics of cholera that occurred in England during 1830–1850 made urgent the need for sanitation and waste management (Gerhard, 1909). ‘Sewage farming’ (the oldest term used in the literature) became relatively common as the first attempt to protect public health and to control water pollution. This technology was mainly developed from 1840 to 1890 in England (Folsom, 1876; Stanbridge, 1976), while in the 1870s the first land treatment systems appeared in the United States, France and Germany (Reed et al., 1995; US EPA, 1979).

During this period important technological innovations took place with regard the treatment potential of land treatment systems. In 1853 the first spray irrigation sewage farm was established at Rugby, England and some years later (1874), an overland flow system was applied to grass plots to remove suspended solids and nutrients from applied wastewater (US EPA, 1979). The development of the intermittent filter in 1870 by Sir Edwin Franklin provided the first scientific evidence that land application is a purification process rather than disposal. The pioneering experiments and demonstration projects of Denton (1871) resulted in the adoption of intermittent filters for wastewater treatment in many cities. In addition, the need for adjusting application rates of wastewater to the purifying potential of the land and the prevalence of aerobic conditions became evident (U.S. EPA, 1979). Concomitantly, it was realized that effluent disposal into fields throughout the year to supply crops with nutrients was not always compatible with crop requirements and could cause adverse effects on crops. Denton (1877) suggested that a combination of intermittent filters and land treatment comprised the ideal wastewater treatment scheme. This observation in fact made land treatment more flexible for wastewater treatment during adverse climatic conditions and crop harvesting. At that period the first book for land treatment was published which entitled Sewage, the Fertilizer of land, Land the Purifier of Sewage.

Some years later, the in-depth work of Rafter and co-workers in USA shed light into basic treatment processes occurring in land treatment systems. In 1887, it was shown that organic matter and nitrogen were oxidized by living organisms, and in 1890, Winogradsky showed that certain species of bacteria were responsible for nitrogen oxidation (Rafter and Baker, 1894). A few years later (1894), Rafter and Baker reported the outstanding ability of intermittent filters to remove bacteria (99.9%) from raw sewage.

By 1876, 35 towns were practising land treatment in Britain, while in USA and Canada this practice was applied by most of the 143 sewage treatment facilities (US EPA, 1979). Some land treatment systems established in the early 1900s (Woodland, Bakersfield,
Lubbock, and Vineland) have been modified over time and continue to operate successfully until today (Crites et al., 2000). Thereafter, the development of land treatment for wastewater management declined in Europe and USA. The development of conventional treatment processes in the late 1880s and the inability of more sewage plants to expand in order to cover increasing population were considered the principal reasons.

The second period of land treatment development: 1905–1972
During that period conventional wastewater treatment plants, including trickling filters and later activated sludge, were increasingly adopted for wastewater treatment in most municipalities. Furthermore, a shift was observed in the basic philosophy regarding wastewater management toward the production of partially treated wastewater to be discharged in water bodies. As a consequence, land treatment systems continued to build up at slower rate in the Europe and USA until 1950. It was estimated that by 1939 125 municipalities applied land treatment (Hutchins, 1939), while the number increased to 2,200 by 1964 in USA including domestic wastewater, food industry effluents and petroleum byproducts (Hill et al., 1964).

The decreasing availability of fresh water sources, especially in the western states of USA and the degradation of their quality due to sea intrusion and eutrophication in the late 1950s renewed again the concern for wastewater application to the land. Emphasis was given at that period to understand the treatment potential of the soil as well as the principal environmental factors affecting the removal of pollutants. Several studies concentrated on issues regarding pathogen removal in the soil and the potential health risks, the hydraulic loading rates, the fate of nutrients and the needs for preapplication treatment (McGaukey et al., 1966). In addition, a large number of projects of effluent reuse initiated at that period including irrigation of agricultural crops, groundwater recharge and recreational uses (US EPA, 1979). Despite the knowledge accumulated during that period about the potential of soil to remove pollutants a return to land treatment did not occur until 1972 when the Clean Water Act was enacted.

The third period of land treatment development: 1972 until today
A partial return to land treatment systems occurred after the passage of Clean Water Act of 1972, which aimed to the protection of natural waters, the beneficial reuse of treated effluent and the elimination of effluent discharge to waterways. Then it was realized that land treatment systems could be used to meet the requirements defined by this law (Reed et al., 1995). At this period the number of land treatment schemes was estimated at 3,400 which consisted of 10 to 20% of wastewater treatment facilities in operation in the USA (US EPA, 1979) while a further increase up to 50% was expected to occur (Costle, 1977).

During the last two decades, there has been renewed interest in the development of land treatment systems for the treatment and beneficial reuse of wastewater. This interest has mainly been caused by: (a) the inability of centralized wastewater treatment plants to serve clusters of homes, isolated rural communities, or institutions, (b) the high construction, operation, and maintenance costs of conventional plants particularly in small communities (<10,000 p.e), (c) the need for further treatment for reuse of effluents that have been treated previously in conventional wastewater treatment plants and (d) their efficiency for wastewater treatment in a wide range of climatic conditions (Paranychianakis et al., 2006). In addition the recognition of the importance of wastewater management in meeting future water demands, preventing environmental degradation, and ensuring sustainable growth is expected to further increase the use of land treatment in the future.

Currently, land treatment systems and particularly slow rate systems are employed in the treatment of various wastewater types including municipal wastewater (Tzanakakis et al., 2000).
et al., 2007), landfill leachates (Hasselgren, 1998), food processing industry effluents (Sparling et al., 2001), meat processing wastewater (Guo and Sims, 2003), olive oil mill wastewater (Cabrera et al., 1996), agricultural drainage (Rhoades, 1989) and contaminated groundwater (Negri et al., 2003). Particular emphasis has been given in the last decade to the production of biomass that can be used for bioenergy and other purposes (Perttu, 1999). Biomass may provide an economic return to municipalities and also contribute in alleviating climate change. Many demonstration and full-scale projects are in operation in northern Europe, Mediterranean Region, Australia and USA. In addition, particular emphasis is given on the development of rapid infiltration systems. Large projects are in operation in Israel, Australia and USA for the artificial recharge of aquifers.

Ecological and health risk issues arising for wastewater application to the land

Waste has played a significant role in history. Bubonic plague, cholera and typhoid fever were diseases that altered the populations of Europe and influenced monarchies toward to waste and wastewater management. Greek ancient civilizations and Romans were aware of the benefits of sanitation and developed innovative hydraulic technologies and practices to protect public health; however issues of environmental protection were not considered at all during this period. Athens, in 500 BC, had the first municipal dump in the western world. Regulations required waste to be dumped at least a mile from the city limits. In following years until the early 1800s the sanitation concept was totally lost (US EPA, 1979). A renewed concern about sanitation appeared during Renaissance while the great epidemics of cholera and typhoid fever in the early 1800s stressed the need for sanitation and the protection of water sources. Although the germ theory had not been developed yet, polluted water sources were considered responsible for the occurrence of diseases. These epidemics motivated the responsible agencies to establish the sanitation requirements by constructing sewerage systems, wastewater treatment units and drinking water treatment and environmental protection policies.

In 1865 the Commission on Towns Sewage Disposal stated that land application was the only way to avoid river pollution and to make a profit through the higher yields by irrigated crops. Furthermore, the Sewage Utilization Acts of 1865 and 1867 prevented the construction of sewers which discharge directly into rivers and ocean. These laws in fact encouraged the adoption of land treatment by municipalities for the management of wastewater. In 1872, the first standards of effluent discharge to rivers were published in England and information was provided about land application. A second report was published in 1884 by a Royal Commission which also encouraged cities to apply land treatment practice. From that period until the beginning of the 20th century many demonstration and full scale projects were established in USA and Britain to investigate the treatment potential of land in order to prevent adverse health effects, and to protect the environment.

The Royal Commission on Sewage Disposal adopted standards for effluent discharge in 1912 that included limits of 20 mg/L for BOD and suspended solids (US EPA, 1979). Few years later in 1914 standards for drinking water quality were suggested in USA which formed the basis for the national standards that adopted in 1974. The first standards for effluent reuse were adopted in 1918 by the California State Board of Health (1918) and they have been continually revised until today to cover new uses and to meet increasing environmental requirements. In 1989 WHO published guidelines for the safe use of wastewater in agriculture (WHO, 2006).

Despite the increasing use of land treatment systems for wastewater management regulations/guidelines that govern the operation of all types of these systems have not set yet. It is somewhat surprising since it has been shown by several studies that effluent
application to the land may result in significant ecological and public health risks (Bouwer, 2000; Paranychianakis et al., 2006). It can be considered however that limits of pollutants and pathogens in wastewater effluent which are applied to the soil must not exceed the limits suggested by the existing regulations or guidelines for effluent reuse. Principal factors that affect the requirements of preapplication treatment are: (a) the degree of public access to the site; (b) the degree of process control the application area; (c) the end-use of the irrigated crop; and (d) the treatment object (e.g. removal of organic carbon, nitrogen, or pathogens). Thus, primary treatment should be acceptable for isolated sites with restricted public access when irrigated crops are not intended for direct human consumption or when effluent application is implemented by subsurface techniques and the underground part of the irrigated crops is not consumed raw. Biological treatment using lagoons or other processes, and strict control of pathogens should be practised in locations with public access or for crops to be eaten raw.

**Conclusions**

Land application of wastewater known as “sewage farming” has been practised for centuries as a mean to manage wastewater, to control pollution and to eliminate risks for public health. Information provided over the years suggest that land application systems, with prudent management, can be compatible with the current high public health and environmental standards adopted by environmental agencies and international organizations and with the sustainable use of land. Land-based wastewater treatment systems appear to be an ideal practice, particularly in arid or semi-arid regions where effluents can be used efficiently for increasing irrigated areas. The use of land-based systems to treat municipal and other types of wastewater is expected to further expand in the future. This expanded use is in response to the high construction and maintenance costs of complex tertiary treatment processes, as well as the need to eliminate disposal of effluents into streams and lakes.

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