Desalination 260 (2010) 211–217

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Options for sustainable sewage sludge management in small wastewater treatment plants on islands: The case of Crete

D. Kalderis [a], M. Aivalioti [b,*], E. Gidarakos [b]

[a] Department of Natural Resources and the Environment, Branch of Chania, Technological and Educational Institute of Crete, Romanou 3, Chania, Crete, Greece
[b] Department of Environmental Engineering, University Campus, Technical University of Crete, Chania, Crete, Greece

ARTICLE INFO

Article history:
Received 13 July 2009
Received in revised form 8 April 2010
Accepted 12 April 2010
Available online 20 May 2010

Keywords:
Sewage sludge
Lime stabilization
Thermal drying
Solar drying
Crete

ABSTRACT

This work examines four essentially different and widely established methods for the treatment of sewage sludge and determines the applicability of each one of them in the economical, geographical and environmental settings of the island of Crete in Greece. Under these conditions, the combination of lime stabilization and solar drying appears to be the optimum solution for sewage sludge management. For each of the treatment technologies considered, cost indicator spreadsheets were developed that enabled the automatic calculation of the total cost. The cost of the lime stabilization–soar drying combined treatment is comparable to the cost of composting or thermal drying alone. The judgment criteria and the economical parameters used for the evaluation of the methods may be a useful tool for other wastewater treatment plants in various Mediterranean islands.

1. Introduction

Sewage sludge is the waste that remains after the treatment of municipal wastewater by wastewater treatment plants (WWTPs). Although it can be transformed to a valuable fertilizer, it is often contaminated by heavy metals, microorganisms and various organic substances. As a result, in 1998, approximately 25% of the sewage sludge produced in Europe was disposed of in landfill sites [1]. The demands set by the EU Directive on Urban Waste Water Treatment, has resulted in many new treatment plants coming into operation throughout Europe [2]. The total amount of sewage sludge has risen from 7.2 million tons of dry matter in 1998 to approximately 9.4 million tons in 2005 [1].

In most EU countries, the disposal of sewage sludge to sanitary landfills has gradually decreased, whereas, the trend for re-use of treated sludge as a soil amendment or as a biofuel has increased. Table 1 shows the trends in sewage sludge management in many European countries between 1992 and 2005. It can be seen that, although landfilling of sludge has not been significantly reduced since 1992, incineration and recycling have increased steadily since then. Recycling includes all the processes that result in re-use of the sludge, such as composting. Several European WWTPs employ co-composting of sludge with either biodegradable residential waste or directly with ‘green’ waste and animal manure. The composted sludge is used in land rehabilitation or as a soil amendment according to EU guidelines.

Incineration of sludge is mainly employed in Germany, France and the Netherlands. It aims at reducing the volume of sludge and rendering it inert (biologically and chemically) before landfilling. However, the process requires significant amounts of energy and is therefore more costly compared to conventional treatment options.

Article 5 of EU Directive 1999/31 states that, by 2016 only 35% of the biodegradable waste produced in 1995 will be allowed to be landfilled [3]. This means that alternative management options are required for sludge. Currently in Europe, one of the most desirable uses of treated sludge is in agriculture as soil amendment. This option is not always applicable due to the strict guidelines that deal with agricultural soil quality and the production of crops. Another preferred route is the use of treated sludge to rehabilitate damaged landscapes.

In Greece, the implementation of EU Directive 271/91/EC concerning urban wastewater treatment resulted in the development of many wastewater treatment units, even in remote areas not covered before. At the moment, the existing wastewater treatment plants serve about 75% of the Greek population nationwide. Inevitably, the quantity of sewage sludge has also increased. As shown in Table 2, the production of sewage sludge has almost doubled in an 8-year period (1996–2002). Contrary to the European trends, the vast majority of sludge is still being landfilled. The delayed implementation of EU Directives has led to further delays in developing alternative management plans for sludge. Co-composting and lime stabilization have been only recently used in some wastewater treatment units. It is interesting to note that ~96% of the produced sludge ends up in landfills, whereas the EU-25 average is ~25%.

* Corresponding author. Tel.: +30 28210 37821; fax. +30 28210 37850.
E-mail address: maria.aivalioti@enveng.tuc.gr (M. Aivalioti).

0011-9164/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.desal.2010.04.030

Table 1
Destination of sludge from WWTPs in selected European countries (in thousands of tons dry matter per year [1]).

		Denmark	Germany	France	Ireland	Netherlands	Portugal	UK	Finland	Austria
1998	Surface water	–	–	–	–	–	–	240	–	–
	Recycling	125	1270	572	25	100	74	672	85	68
	Landfill	25	744	92	17	108	147	118	65	58
	Incineration	50	558	214	–	150	–	144	–	66
	Not specified	–	89	–	1	23	25	19	–	4
	Total	200	2661	878	43	381	246	1193	150	196
2000	Surface water	–	–	–	–	–	–	–	–	–
	Recycling	125	1334	640	65	110	104	1014	90	68
	Landfill	25	608	71	35	68	209	111	60	58
	Incineration	50	732	269	–	200	–	326	–	66
	Not specified	–	62	–	–	23	35	19	–	4
	Total	200	2736	980	100	401	348	1470	150	196
2005	Surface water	–	–	–	–	–	–	–	–	–
	Recycling	125	1391	765	84	110	108	1118	115	68
	Landfill	25	500	–	29	68	215	114	45	58
	Incineration	50	838	407	–	200	–	332	–	65
	Not specified	–	58	–	–	23	36	19	–	–
	Total	200	2787	1172	113	401	359	1583	160	195

Andreadakis et al. [4] attempted to assess the quality of the produced sludge in several urban WWTPs in Greece, with respect to potential agricultural use. They concluded that at the moment, landfilling is the only applicable option, however, the implementation of EU Wastewater Directive (91/271/EEC) will improve the quality of sludge and the agricultural use of treated sludge will be a more feasible option in the near future. Table 3 shows the physicochemical characteristics of sewage sludge from 6 major Greek WWTPs against the standards set by EU Directive 86/278 and U.S. EPA. The sludges are of adequate quality, indicating that they could be potentially used in agriculture as soil amendment. At the moment, however, a legal framework for this option does not exist and the agricultural use of sludge is not socially acceptable yet. Practically, the only option is to use various established technologies to improve the sludge characteristics and/or reduce its volume before landfilling.

2. Description of major WWTP in Crete

The island of Crete is located in the south part of Greece and is one of the largest islands in the Eastern Mediterranean. The four largest cities of the island are Heraklion (population ~160,000), Chania (~80,000), Rethymno (~50,000) and Agios Nikolaos (~20,000). Fig. 1 shows the location of the island of Crete.

In all cases except the WWTP of Rethymno, the final product is dewatered sludge, the characteristics of which are shown in Table 4. In Rethymnon, dewatered sludge is stabilized using 10% lime and is then air dried. The final product, consisting of 65% solids, is used as a landfill cover material. In all other WWTPs, the dewatered sludge (total solids 20–25%) is deposited in sanitary landfills. The sludge quantities and solids concentration for the WWTPs of each municipality are shown in Table 4.

Table 2
Sewage sludge disposal options in Greece [4].

	1996	1998	2000	2002
Dry weight (tons/year)	52,000	68,000	76,000	92,500
Used in WWTPs (in situ)/%	1.3	1.2	1.3	1.2
Agriculture/%[a]	0.2	1.3	1.3	1.3
Composting/%	–	1.0	0.9	1.0
Landfills/%	98.1	96.2	96.1	96.1
Forests (as soil amendment)/%	0.4	0.4	0.4	0.4

[a] This percentage corresponds to an estimation from local farmland owners, since up to date a national legal framework does not exist for this option.

3. Current problems and challenges in municipal wastewater treatment in Crete

Until recently, all sludge produced from WWTPs in Greece was disposed of without further treatment in sanitary and unsanitary landfills. This practice was preferred due to the low cost associated with the transportation and uncontrollable disposal of the sludge. The need for a permanent solution to the problem of sewage sludge management has resulted from the recent implementation of EU Directive 1999/31 that calls for a gradual reduction in the biodegradable waste that end up in landfills. Additionally, the implementation of EU Directive 91/271/EU calls for exploitation of sewage sludge whenever possible. In order to re-use sewage sludge, for example, as a landfill cover or as a soil amendment, the levels of moisture, heavy metals and pathogenic microorganisms must be reduced.

Crete is a highly touristic island that almost doubles its population during the summer months. This increase in population has also increased the quantity of sewage sludge produced in all WWTPs. As a result, the capacity and subsequently the life time of the main landfills of the island have been greatly reduced. The uncontrollable disposal of

Table 3
Quantities and characteristics of sludges produced from selected WWTPs in Greece [4].

	Ioannina	Kos	Kalamat[a]	Lamia	Veria	EU 86/278	U.S. EPA[a]
Capacity (×1000 p.e.)	105	20	60	67	70		
Organic loading	M	L	L	L	M		
Pretreatment of sludge	AnD	AerSt	AerSt	AerSt	–		
N (%)	10.6	8.1	7.2	10.6	10.0		
P (%)	7.8	2.1	4.5	2.9	4.3		
TS (%)	18.8	34.1	18.1	18.9	–		
VS (%)	51.0	30.0	59.8	58.6	57.1		
Ni (mg/kg DS)	65	30	34	72	59	300–400	420
Zn (mg/kg DS)	2380	633	1857	1332	1908	2500–4000	2800
Cr (mg/kg DS)	31	67	34	98	60	–	1200
Cd (mg/kg DS)	4.1	3.2	3	2.9	2.9	20–40	39
Cu (mg/kg DS)	149	333	117	236	103	1000–1750	1500
Pb (mg/kg DS)	223	169	116	125	55	750–1200	300

M: Medium (0.20–0.60 kg BOD/kg SS), L: Low (<0.20 kg BOD/kg SS).
AnD: Anaerobic Digestion, AerSt: Aerobic stabilization.
[a] Standard limits for agricultural use of sludge.