Waste Management 33 (2013) 1461–1468

Contents lists available at SciVerse ScienceDirect

Waste Management

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

Innovative reuse of drinking water sludge in geo-environmental applications

D. Caniani, S. Masi *, I.M. Mancini, E. Trulli

Dept. of Environmental Engineering and Physics, viale dell'Ateneo Lucano, 10, 85100 Potenza, Basilicata, Italy

ARTICLE INFO

Article history:
Received 6 September 2012
Accepted 8 February 2013
Available online 11 March 2013

Keywords:
Bio-soils
Drinking water sludge
Municipal solid waste
Reuse
Stabilized organic fraction

ABSTRACT

In recent years, the replacement of natural raw materials with new alternative materials, which acquire an economic, energetic and environmental value, has gained increasing importance. The considerable consumption of water has favoured the increase in the number of drinking water treatment plants and, consequently, the production of drinking water sludge. This paper proposes a protocol of analyses capable of evaluating chemical characteristics of drinking water sludge from surface water treatment plants. Thereby we are able to assess their possible beneficial use for geo-environmental applications, such as the construction of barrier layers for landfill and for the formation of "bio-soils", when mixed with the stabilized organic fraction of municipal solid waste. This paper reports the results of a study aimed at evaluating the quality and environmental aspects of reconstructed soils ("bio-soil"), which are used in much greater quantities than the usual standard, for "massive" applications in environmental actions such as the final cover of landfills. The granulometric, chemical and physical analyses of the sludge and the leaching test on the stabilized organic fraction showed the suitability of the proposed materials for reuse.

The study proved that the reuse of drinking water sludge for the construction of barrier layers and the formation of "bio-soils" reduces the consumption of natural materials, the demand for landfill volumes, and offers numerous technological advantages.

1. Introduction

The most important drinking water system in Southern Italy is the Acquedotto Pugliese, whose water network, 15,000 km long, is the longest in Europe. Its six purification plants (Sinni, Pertusillo, Fortore, Locone, Camastra and Metapontino) treat 11,000 l/s of surface water, generating around 70 ton/day of sludge, and creating a total amount of around 25,200 ton/year.

If we hypothesize the purification of about 70% of the water volumes needed for meeting the needs of the Italian population and a moisture content of the sludge produced equal to 70%, we obtain a yearly production of sludge equal to 270,000 ton/year which could be compared to the yearly production of the urban solid waste of the whole Italian region of Basilicata (600,000 inhabitants). The daily drinking water sludge production on a world scale is increasing more and more: at present, it exceeds 10,000 ton/day.

In 2009, the production of municipal solid waste (MSW) in Italy was 32.1 million tons. More than 20% of the MSW production is composed of an organic undersieve fraction, which undergoes an aerobic stabilization, in order to reduce its hazard for the environment. This organic fraction is converted into a stabilized organic fraction, SOF, and afterwards is dumped in landfills. Considering the increasing and renewed environmental awareness, the identification of suitable application fields of these new materials is extremely important in order to prevent their disposal.

In 1998, in a landfill area located near Valencia, Ingelmo et al. carried out an experiment to verify the possibility of making vegetation take root by replacing the usual top layer which was made up of fertile vegetable soil with a thin layer of inert soil covered with a much thinner surface layer of organic waste materials. In order to assess the best characteristics of this latter layer, they carried out trials on parcels treated with dry sludge or with SOF, or characterised by an absence of organic matter (Ingelmo et al., 1998).

Studies carried out in a quarry near Gerona (Spain) verified the evolution of organic chemical compounds in soils treated with drinking water sludge (Molina et al., 2000).

From July 2002 to November 2004, the Italian region of Piedmont, together with the Italian Institute for Wood, Plants and the Environment (I.P.L.A.), carried out a set of trials on land parcels which were constituted by using SOF and soil in different proportions and methods (mixing or stratification), or containing pure soil and soil added with a compost from the treatment of sludge and green fraction. In order to assess the best mixing ratios for the mixtures of sludge and SOF, some studies were carried out by analysing the sludge from a wastewater treatment plant. Mixtures of sludge, SOF and Clinoptilotite were analyzed to produce compost. Clinoptilotite was added due to its ability to store up heavy metals (Zorpas et al., 2000). Further hypotheses of mixing sludge and SOF were studied (Delgado et al., 2004). Stability

* Corresponding author.
E-mail address: salvatore.masi@unibas.it (S. Masi).

0956-053X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.wasman.2013.02.007

analyses were carried out on mixtures of sludge and SOF and on the separated materials (Delgado et al., 2004).

Moreover, several biological assays have been combined with standard chemical analyses. Multiple studies showed that the chemical approach does not provide satisfactory tools to define the environmental risk associated to a mixture of pollutants (Pasini et al., 2000). Information about phytotoxicity is necessary for the evaluation of the environmental risk of pollution (Wang et al., 2001). The presence of toxicological agents can be detected by analysing the changes caused on a test organism. These tests are reliable, convenient, fast and simple (Valerio et al., 2007). Laboratory tests can be divided into acute and chronic (or sublethal) tests. An acute test uses increasing doses for short periods, from 15 min to 96 h. Chronic tests have a duration variable from days to months and are conducted typically using low concentrations for long periods. The use of plants offers an advantage if compared to other organisms, because they may be more sensitive to environmental stress (Valerio et al., 2007). Furthermore, the use of ecotoxicological assays allows us to evaluate, on one side, the bioavailable fraction of the pollutants, and, on the other hand, any synergy and/or antagonism phenomena of different substances (Pasini et al., 2000).

The *Spartium junceum* (or Spanish Broom) is a test organism used for structuring chronic bioassays. In fact, it is suitable for carrying out revegetation activities on closed landfills and it is capable of adapting itself to difficult soils, such as dry or clayey soils. A Spanish Broom plantation brings a considerable increase in cohesion in the surface layers of the soil (Preti and Giadrossich, 2009). In literature, there are different experiences of using biological assays to evaluate the effects of heavy metals on living organisms. In 2007, Valerio et al. attested the potentialities of the use of bioassays on lettuce for the determination of phytotoxicity of elements with high solubility in soils.

In this research paper, an analytical protocol is designed to test the suitability of drinking water sludge mixed with municipal solid waste stabilized organic fraction, SOF, in order to create innovative ''bio-soils'' to be used for daily and final covering in controlled landfills. We applied environmental bioassays, in order to test the proposed reuse scenario. Vegetation tests were used to evaluate the toxicity of some heavy metals on vegetable species by varying the growth substrate, and an innovative test with *Spartium junctium* was applied. The objective of this research was to assess the chemical–physical characteristics of such waste materials in order to meet the specific needs for reuse in the fields they are meant for. The subjects of the study were the sludge produced by the drinking water treatment plant of ''Masseria Romaniello'' (Potenza, Southern Italy), which is fed by the Camastra artificial lake, and the SOF coming from the plant of bio-mechanical treatment of Venosa (Potenza).

2. Materials and methods

The analysis protocol proposed in this study assesses: the main physical and chemical characteristics of the materials to be tested when they are mixed with different substrates, the possible percolation of pollutants in groundwater, the variation in the dry matter production of the epigeal biomass, the Germination Index and the Inhibition of the Growth Radical Index. Therefore, the analysis protocol is able to describe the influence of the analyzed materials on soil receptors, vegetation material and groundwater resources.

2.1. The materials used for the experiments

The drinking water sludge (Fig. 1d) comes from the surface water purification plant of ''Masseria Romaniello'', which treats the water collected in the Camastra dam and is located in the town of Potenza (Southern Italy). This purification plant has a capacity of 1050 l/s and produces about 3 tons of sludge a day, creating a yearly quantity of around 1095 tons. It is worth underlining how its reuse in industrial productions is characterised by some technological and economic limitations. Drinking water sludge, in fact, is characterised by a high moisture content that is on average between 70% and 80%. Such a characteristic makes transportation to places far from the production sites inconvenient, thus limiting the practical possibilities of reuse. The sludge treatment plant includes gravity thickeners, filterpress and beltpress. The reagents used in the different stages of water treatment of the ''Masseria Romaniello'' drinking water treatment plant are: chlorine dioxide, carbon dioxide, aluminum and polyvinyl organic flocculent – anion only at the stage of the sludge dehydration. The treatment outline involves an enrichment of aluminum sludge as a result of the use of polyvinyl aluminum as a coagulant reagent. The SOF used for the experimental work comes from a bio-mechanical plant for the treatment of MSW coming from small urban settlements in the northern province of Potenza (Basilicata Region, Sothern Italy). The cycle of treatment is articulated into two phases: opening of the plastic bags and dry–wet separation with a slowly rotating cylindrical sieve. These treatments provide a very small tearing of plastic fractions and a low breakage of glass components.

Only the fraction characterized by a dimension less than 80 mm (undersieve) undergoes a stabilization process in aerated bioreactors (biocells) of 25 m^3. The cycle of treatment involves the permanence in the biocell for a time sufficient to ensure an adequate degree of stabilization of the treated material. The process determines the development of bio-oxidative processes in thermophilous times ranging from 8 to 14 days. The processing time depends on the biological stability level desired. The plant in question operates on a cycle of 14 days to obtain a potentiality equal to 16–20 ton/day.

The material extracted from the biocells underwent a first stage of refining aimed at eliminating the inert matter and coarse fractions. The operation was conducted in a drum sieve with a mesh of 20 mm. The screening resulted in 41% decrease in the weight of the material. For the experimental tests, the material exiting from biocells was further refined with a rotating screen at 10 mm. Afterwards, the material was sampled and subjected, for further 60 days, to a maturation phase without forced ventilation. At the end, we proceeded to form the test samples by mixing the obtained SOF with inert structuring fractions and drinking water sludge, which was used as a corrector of granulometry.

2.2. Granulometric analysis of drinking water sludge

Sludge is characterised by a high water content, marked hydrophilia, and scarce or absent biological activity. In the sludge, we noticed the presence of hydroxides, which originate from coagulating agents, colloids, organic matter and inorganic precipitates. The sludge underwent a granulometric analysis, performed at the Geotechnical Laboratory of the Department of Structures, Geotechnics, and Geology, at the University of Basilicata.

2.3. Preliminary laboratory analyses: determination of heavy metals and leaching tests

The operation for separating solid and liquid phases was carried out according to the method codified by the Italian Agency for Environmental Protection and Technical Services (APAT, 2003). The analytical determination of contaminants in the mixture was based on the methods of the Italian Water Research Institute (IRSA, 2006). The metal content in SOF and sludge was analyzed according to the methods set down by the Italian Environmental