MANAGEMENT PRACTICES OFWASTEWATER SLUDGE

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ABSTRACT

Large amounts of wastewater sludge, a secondary pollutant of wastewater treatment plants, commonly containing over 90% water and pathogens, organic pollutants and heavy metals, are produced daily worldwide. Main treatment routes of wastewater sludge are: landfill, anaerobic digestion, land application and incineration. Anaerobic sludge digestion is a technology employed worldwide to reduce solids, stabilize organic matter, and destroy pathogens and to produce biogas as a source of energy.Compositing is applied for sludge treatment and conversion of complex biowaste into a stabilized product that can be used as organic fertilizer in agriculture. In this paper we present the main practices employed in the management of wastewater sludge, in order to reduce its volume, to capitalize it and to protect the environment.

INTRODUCTION

The aim of municipal wastewater treatment plants is to separate solids from water, and to disinfect them to different degrees by removing the organic and inorganic pollutants, which may be toxic to humans or have hazardous effects on the environment.

Sludge refers to the solid, semisolid, or slurry residual material which is left behind from the treatment of wastewater. It is an unavoidable by-product of wastewater treatment plants and contains many toxic substances such as pathogens, heavy metals (Mn, Zn, Cu, Co, Ni, B, Mo, As, Cd, Hg, Pb) and organic contaminants, which can lead to serious environmental pollution. In addition to the pollutants mentioned above, sludges also contain compounds of agricultural value (organic matter, nutrients: nitrogen and phosphorus, potassium and in small quantities calcium, sulfur and magnesium).

Primary sludge is composed by the capture of suspended solids and organics in the primary treatment process, through screening, grit removal, flotation, precipitation and sedimentation. Primary sludge contains2-9% solids, the remaining 90%, (sometimes 99.5%) being water [18]. This type of sludge has high biodegradability.

Secondary sludge is the sludge produced by biological processes such as the activated sludge process. This type of sludge contains flocs (Fig. 1) formed of microorganisms growing on organic and inorganic substances, extracellular polymeric substances (proteins, humic-like substances, polysaccharides, lipids and nucleic acids) excreted by bacteria, recalcitrant organics originating from wastewater or formed during bacterial decay, and inorganic particles from wastewater [20].

The total solids concentration is between 0.8-3.3%, depending on the type of biological treatment process, and the rest is water [8]. Waste activated sludge has low biodegradability.

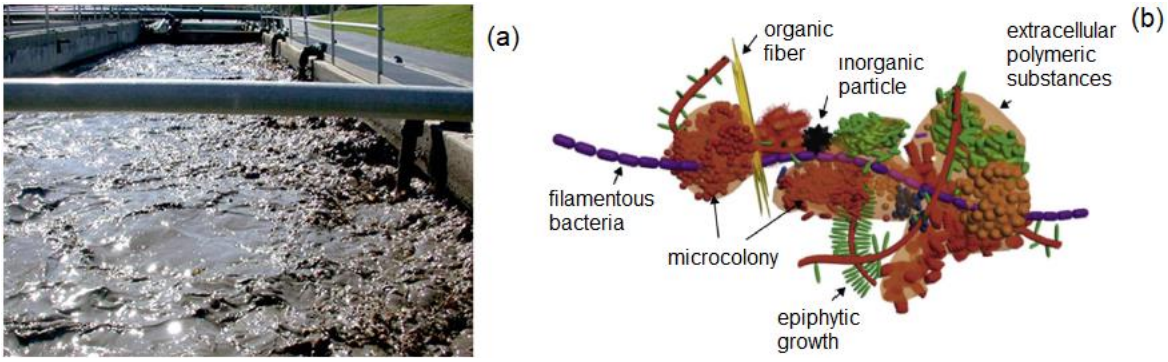

Fig. 1. Primary sludge aspect (a) and detail of activated sludge flocs (b) [15]

Sludge properties are mainly determined by the size, shape, density and strength of sludge flocs [6].

The characteristics of sludge depend on the degree of pollution, the nature of the pollutants in the wastewater subjected to treatment and the methods of treating the sludge.

Large amounts of sludge are generated worldwide in wastewater treatment plants. The average annual production of excess sludge is 3millionwet tons in Australia, and 240 millionwet tons in Europe, USA and China combined [16]. More than 10 million tons of dry solids of sludge were produced in 26 Member States in 2008, and the sludge amount is expected to continue to grow up to 13 million tons by 2020 [8].

The sludge resulting from urban wastewater treatment plants comes from different stages of the wastewater treatment processes, is considered as waste which is subject to waste regulations and must be disposed of. There are many established pathways for handling, treating, disposing and using sludge. However, sludge management continues to pose major environmental, financial, technical and regulatory challenges for system owners [17].

Sludge treatment is one of the most significant issues in wastewater treatment, due to higher energy demands and treatment costs [21].

MATERIAL AND METHOD

Quite often, the primary sludge and waste activated sludge are combined together for further treatment and disposal.Two basic goals of treating sludge before its final disposal are to reduce its volume and to stabilize the organic matter. Stabilized sludge does not have an offensive odour and can be handled without causing nuisance or health hazard. Also, smaller sludge volume reduces the costs of pumping and storage.An overview of the pretreatment methods adopted for transforming and concentrating raw and wet sludge is presented in Figure 2.

Because the water content of the sludge is high, it must be dewatered before treatment, usually by belt filters, press filters, settling centrifuges and sludge mineralization beds.Sludge dewatering step accounts for 50-60% of the operating costs in wastewater treatment plants [7].After mechanical treatment, dewatered sludge can be transported by truck to the landfill for final disposal.

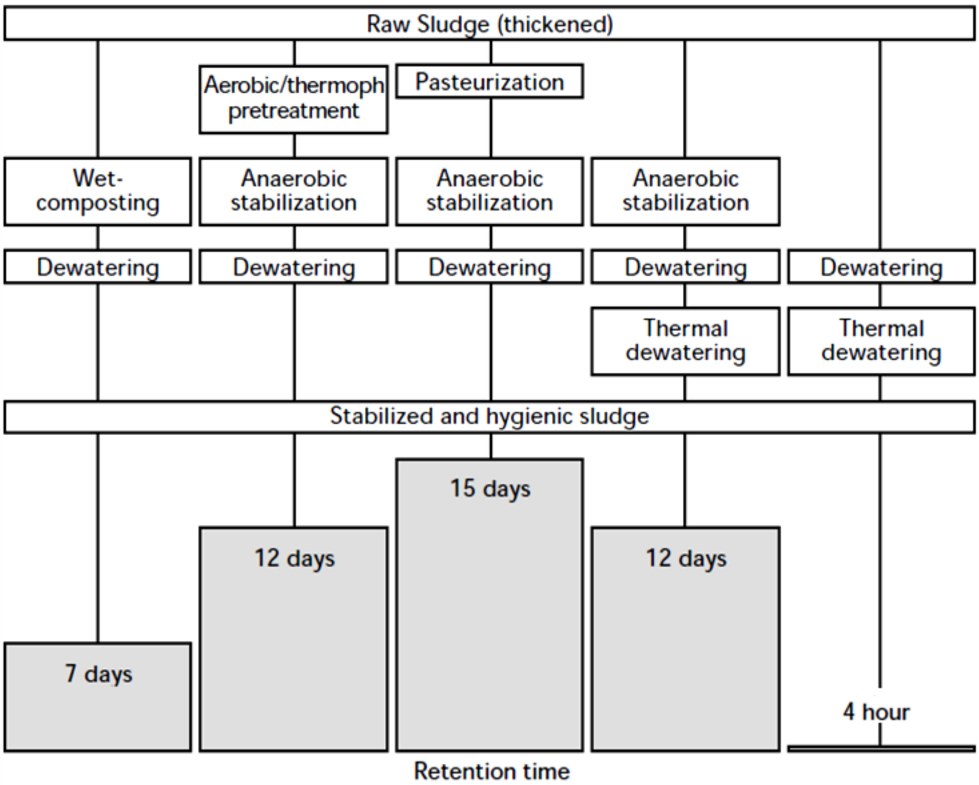

Fig. 2. Methods of sludge pretreatment [25]

More sustainable actions would be to capitalize the sludge by anaerobic fermentation, because the produced biogas can be further valorized for electricity and heat cogeneration, or by gasification of the dried sludge to further support heat and electricity production (with very small delivery of residues tolandfill) [4]. Also, if the sludge is incinerated, the ashes can be used as fertilizer, if not too contaminated. If the sludge is not contaminated with unwanted heavy metals or harmful substances not yet broken down, it can be used as fertilizer in agriculture or in silviculture [9], directly or after composting [8]. Sludge may contain toxic industrial chemicals, so it is not spread on land where crops are grown for human consumption.Sludge is alsodisposed in oceans, or used for production of cement, bricks and asphalt

[8]. Frequently usedmethods for the treatment and disposal of wastewater sludge are presented in Figure 3.

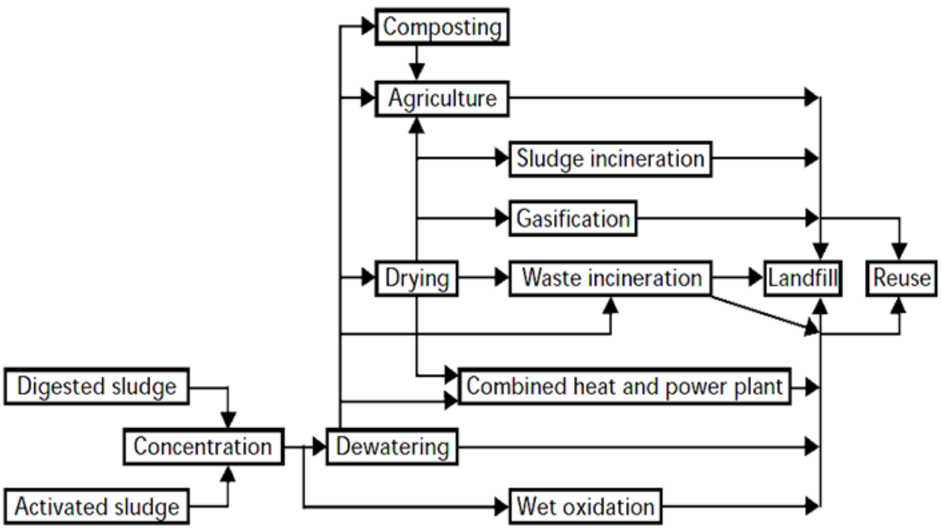

Fig. 3. Treatment and disposal routes for sludge[25]

A detailed sludge management flow is presented in Figure 4 and includes the application of pretreatment as single or in combination.

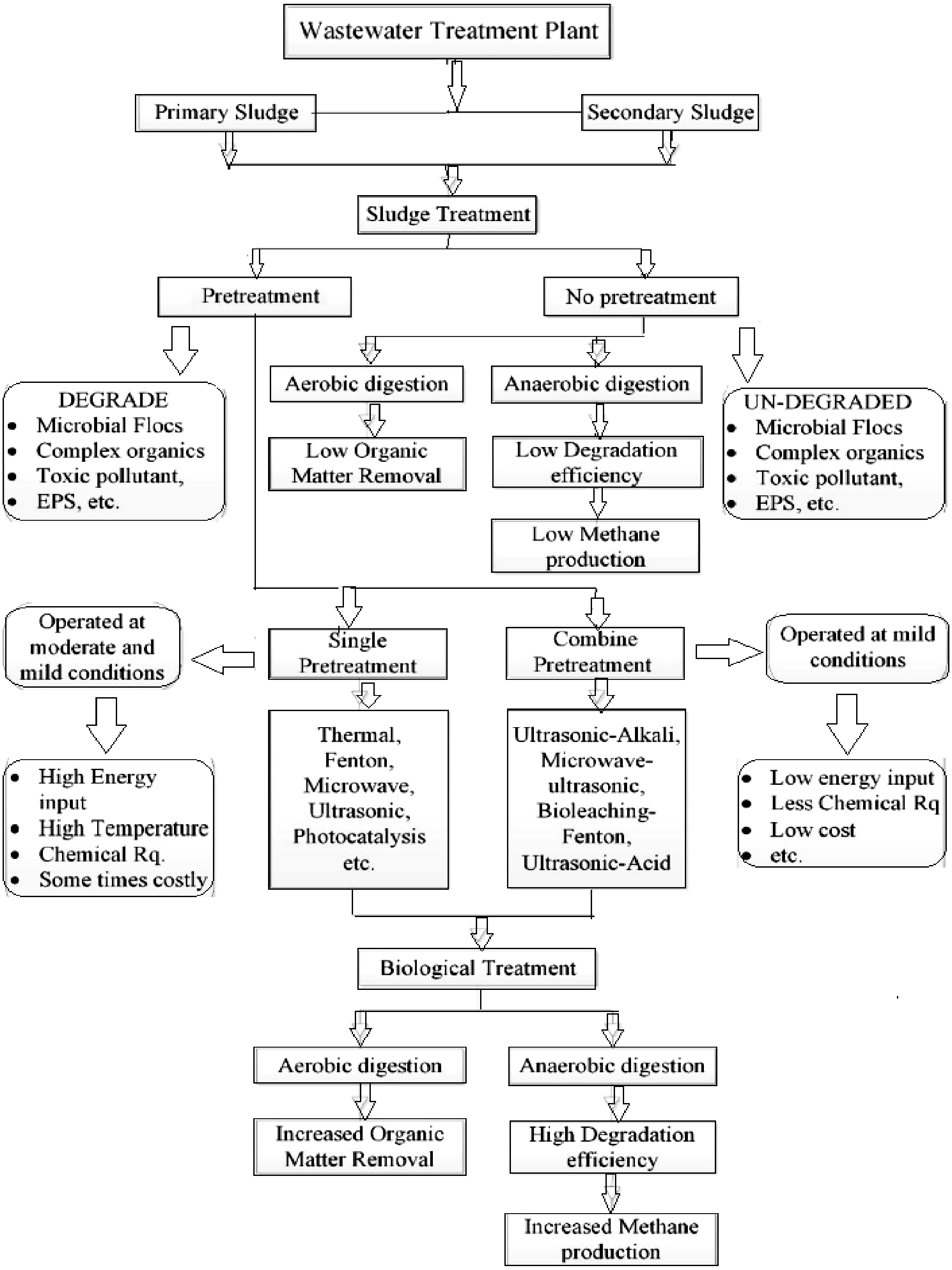

Fig. 4. Sludge management flow chart [2]

Inovations in sludge management practices, that includesthe operations of production, characterisation, stabilisation, digestion, thickening, dewatering, thermal processing, agricultural reuse, production of usable materials, and ultimately disposal, take into account that sludge is not seen as a waste but as a renewable source of energy, nutrients, organic matter and water [32].

RESULTS AND DISCUSSIONS

Traditionally, sludge is treated by extended aeration when the size of a wastewater treatment plant is too small, so is unfeasible to install an anaerobic digester. For large wastewater treatment plants, stabilisation by anaerobic digestion is preferred [13].

Anaerobic digestion (AD) is a multistep biological process allowing converting various types of organic waste, including sewage sludge, into a renewable energy, the biogas (composed mainly of CH_4 and CO_2) and digestate.The anaerobic digestion can be be thermophilic, when the sludge is fermented in tanks at 55°C, or mesophilic, at 36°C.

Anaerobic digestion has the ability to considerably reduce the final solids, as well as destroying most of the pathogenic microorganisms in the sludge. 50% of the costs at a wastewater treatment plant are associated with sludge processing [1].

When digesting only wastewater sludge, the yield of CH_4 is low because the sludge has low C/N ratio, but this drawback can be overcome by co-digestion (mixing of wastewater sludge with other substrates richer in carbon, such as animal manure, slaughterhouse waste, food waste, grass, algae etc.) [5]. However, co-digestion might also create synergisms between substrates, dilute inhibitory/toxic compounds and/or enhance the digestate stability [14].

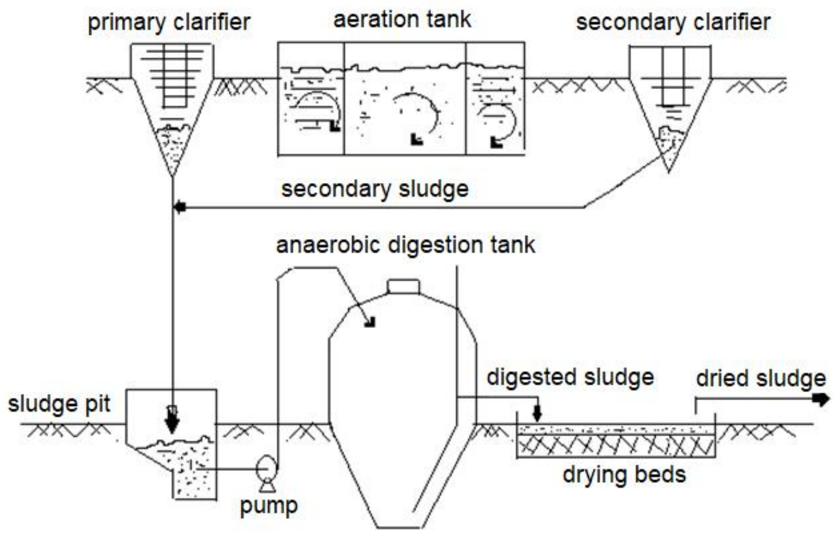

Fig. 5. Diagram of sludge processing in mechanical-biological treatment plant [19] and egg-shaped sludge digesters [23]

Biogas is renewable energy. The methane can be used to generate heat and electric power in cogeneration units while reducing the carbon footprint and greenhouse emissions of the wastewater treatment plant. After sludge digestion, the digestate can be stabilized for landfill or used as fertilizer, depending on its composition and local legislation [31].

*Compositing*is classified as waste-free technology. This method is applied for sludge treatment and conversion of complex biowaste into a stabilized and value addedproduct that can be used as organic fertilizer. Compositing takes place in aerobic conditions where the microaeration can be effective to hydrolyse complex substances into simple materials due to production of hydrolytic enzyme and increase the specific growth rate of the microorganisms [2].

Sludge has be mixed with structural materials rich in carbon, such as sawdust, wood chips ,straws, crop residues, animal marure, bedding, food by-products, municipal solid waste, in suitable proportion, to obtain a C:N ratio of about 30:1 in the compost [11]. For example, by composting the sludge mixed with vegetable waste (Fig. 6) one can obtain a compost with high agronomic value.

Fig. 6. Composting of sludge in sewage treatment plants [24]

Composting takes place at a temperature of 55ºC, which imitates an accelerated natural process that takes place on open floor, where the organic material is broken down, thereby its volume is reduced and the material is converted to more stable organic material.

Although composting has some drawbacks (sludge complex characteristics, temperature loss or the presence of pathogens, unavailability of microorganisms, and the compliance with the requirements for organic fertilizers), this process is still applied at large scale worldwide [8].The chemical composition of sludge makes it an important source of organic matter for soil and nutritive elements for crops. Soil amelioration by application of raw or treated sludge on agricultural land, can significantly reduce the costs of sludge disposal while ensuring the necessary nitrogen and phosphorus of many crops [22].

The use of sludge in agriculture is an old practice in the European Union and accounts for 40% of the total sludge produced in Member States [26]. Pollutants and the possibility of hygienic contamination have raised scepticism towards the agricultural use of sludge. Sewage Sludge Directive 86/278/EEC seeks to encourage the use of sewage sludge in agriculture and to regulate its use in such a way as to prevent harmful effects on soil, vegetation, animals and man. To this end, it prohibits the use of untreated sludge on agricultural land unless it is injected or incorporated into the soil [27].

In Romania, sludge valorization in agriculture is regulated byOrder 344/2005, atransposition into the national legislation of Directive no. 86/278/EEC on the protection of the environment andsoil, when using sewage sludge in agriculture.Owners of treatment plants are obliged to refurbish the plants, to improve the quality of sludge, to ensure its treatment for stabilization and to find users in agriculture or other fields. If sludge composition does not allow its spreading on land, it will be treated by incineration or co-incineration [29].

Landfill disposal of sludge is less used due to high impacts of leachate production and CO_2 emissions directly in air [10]. Current sludgeto-landfill methods generally involve mixing the concentrated sludge with other solid waste in municipal landfills.In Europe, between 2000 and 2009, only Italy, Danmark and Estonia have reported an increase of landfill use [8].European Member States have to reduce the sludge landfill disposal from 25% to 5% by 2020, in line to the Directive 86/278/EEC [3].

Incineration of sludge has increased in many European countries, due to the large volume reduction in sludge and thermal efficiency [12].The main driver for sludge incineration is the fact that the amount of sludge generated at municipal wastewater treatment plants is very large compared to the land area available for sludge disposal or treatment.

Sewage sludge can be incinerated in mono-incineration or co-inceneration plants. Sludge is commonly incinerated in large central plants or as additive in coal fired power stations or in cement kilns [30].To save fuel and transportation costs, and to avoid the dependency from power generators who burn sludge at their power plants, sludge should be incinerated on site, at wastewater treatment plants.Energy from the incineration of sludge can be recovered as green energy source. Depending on their calorific value of the sludge being incinerated, pre-drying of the sludge and pre-heating of the combustion air may be necessary.Sludge drying and incineration should be made side by side.Mechanically dewatered sludge cannot be incinerated auto thermally, reaching 850°C without using auxiliary fuel.

The latest Eurostat data regarding the total production of sludge in Europe are presented in Table 1,with the total amounts of sludge that are disposed by three methods: agricultural use, composting,respectively landfill.

Table 1

Sewage sludge production and disposal (thousand tonnes) in Europe, in 2017 [28]

Country	Total production	Total disposal	Agricultural use	Composting	Landfill
Belgium	n.a.	151.65	30.62	n.a.	0
Bulgaria	68.6	45.3	22.5	3.8	6.8
Chechia	223.27	223.27	102.94	73.06	22.28
Denmark	n.a.	n.a.	n.a.	n.a.	n.a.
Germany	n.a.	n.a.	n.a.	n.a.	n.a.
Estonia	n.a.	n.a.	n.a.	n.a.	n.a.
Ireland	58.773	58.773	46.487	10.065	0.087
Greece	n.a.	n.a.	n.a.	n.a.	n.a.
Spain	n.a.	n.a.	n.a.	n.a.	n.a.
France	1,174	809	299	318	13
Croatia	17.6	3.368	1.086	0.003	1.927
Italy	n.a.	n.a.	n.a.	n.a.	n.a.
Cyprus	n.a.	n.a.	n.a.	n.a.	n.a.
Latvia	24.94	24.471	3.316	5.716	0.022
Lithuania	42.488	40.874	20.817	16.7	3.209
Luxembourg	8.618	8.618	1.138	4.557	n.a.
Hungary	264.71	232.1	28.2	138.44	1.27
Malta	10.3	10.3	0	0	10.3
Netherlands	n.a.	n.a.	n.a.	n.a.	n.a.
Austria	n.a.	n.a.	n.a.	n.a.	n.a.
Poland	584.454	584.454	108.52	25.899	15.25
Portugal	n.a.	n.a.	n.a.	n.a.	n.a.
Romania	283.34	283.34	35	1.76	168.45
Slovenia	36.7	36.6	0	0.4	0.3
Slovakia	54.52	54.52	0	24.62	7.86
Finland	n.a.	n.a.	n.a.	n.a.	n.a.
Sweeden	n.a.	n.a.	n.a.	n.a.	n.a.
United Kingdom	n.a.	n.a.	n.a.	n.a.	n.a.
Iceland	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	n.a.	121.3	66	33.8	16.9
Switzerland	n.a.	n.a.	n.a.	n.a.	n.a.
Albania	98.12	98.12	10.3	n.a.	n.a.
Serbia	13.3	13	n.a.	n.a.	13
Turkey	n.a.	n.a.	n.a.	n.a.	n.a.
Bosnia and Herzegovina	9.5	1.3	0	0	1.3

(*n.a. – data not available)

Netherlands, Belgium and Switzerland have forbidden or restricted the agricultural disposal of sewage sludge and chose to incinerate it. Finland, Estonia and Norway use the composted sludge for green areas. Iceland, Malta and Greece are or have been completely disposing to landfill. In Russia and Belarus, collecting sludge to sludge pits or ponds is common.

According to Eurostat, in 2017, Poland was the largest producer of wastewater sludge with 584.454thousand tons dry substance, of which108.52 thousand tonnes were disposed for agricultural use, 25.899 thousand tonnes were composted and 15.25 thousand tonnes were sent for landfill disposal [28].

In 2017, Romania produced a total of 283.34 thousand tonnes of dry substance sewage sludge, of which 35 thousandtonnes were disposed for agricultural use, 1.76 thousand tonnes were compostedand 168.45 thousand tonnes were sent for landfill disposal. Evolution of sludge quantities generated in Romanian wastewater treatment plants shows a growing trend, from 134 thousand tonnes of dried sludge in 2005 to 520 thousand tonnes of dried sludge in 2018 [28].

Luxembourg was the smallest producer of sludge in 2017, with a total of 8.618 thousand tonnesof dry substance, of which 1.138 thousand tonnes were disposed for agricultural use, 4.557 thousand tonnes were composted and no data reported for landfill disposal [28].

Sludge management must be integrated in all municipal wastewater treatment plants. It is important to valorize the nutrients in the sludge, to make use of its material and energy, and to dispose of it efficiently and sustainably.

Sludge management is dependent on restrictions, incentives and policies in agriculture and energy, adopetd by each country.

CONCLUSIONS

Wastewater sludge is naturally produced in large quantities in wastewater treatment plants, and its treatment and disposal have become a global problem.

Year by year, sludge quantities continue to grow as new wastewater treatment plants are built and the existing ones are being upgraded to keep up with the growing population.

Typically, sewage sludge consists of primary sludge separate from wastewater during pre-settling, and biological excess sludge from the activated sludge system.Sludge must be dewatered to reduce its volume and subsequent disposal costs.

Main treatment routes of sludge are: landfill, anaerobic digestion, land application and incineration. With many available possibilities for sludge treatment and valorization, the selection of the most effective and sustainable way for sludge management is a challenge for wastewater treatment authorities.

Land application of sludge must be carried out with strict limits on heavy metals, emerging contaminants and pathogens.

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