Sewage Sludge Removal and Valorification from the Circular Economy's Point of View

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Abstract: *In this article, we wanted to present the theoretical notions from the specialty literature that have to do with the generation and capitalization of sewage sludge, correlating the beneficial results of the technical process with the life quality degradation consequences on the globe, highlighting the main problems that the humanity faces, but mainly Romania.*

Keywords: *Sewage sludge, capitalization, deposit*

1. Introduction

In the context of climate changes, of massive development of industry, and the increase of population, a major issue that the humanity faces is the lack of water caused by the consumption increase and its quality degradation because of pollution.
Industrial wastewater discharges that are treated improperly or untreated and the infiltrations from agricultural activities directly into the groundwater degraded the water quality in the world.
Sewage sludge's problem is a specific one because the quantity of mud is pretty large and its processing and utilization is complicated and expensive. The solution that almost all the countries have adopted is the reduction of the mud volume that has to be eliminated outside of the wastewater treatment plant.
Sewage sludge processing means considerable costs for dehydration, stabilization and disinfection. After 2015, when the package of measures for the transition to a "circular economy" has been adopted with the purpose to minimalize the quantity of waste and to increase recycling, Romania established a package of measures [1].

- Increasing the recycling rate;
- Increasing the quality of recycled materials;
- Reducing the impact on the environment
- Implementing the concept of "life cycle analysis" in the waste management policy
- Encouraging the production of energy from waste, etc.

According to FAO's AQUASTAT database, 56% of the freshwater catchments at global scale are released in the environment as wastewater (through the form of industrial effluents and agricultural drainage water) and the rest of 44% are consumed for the irrigation of farmland [2].

2. The Formation of MUD

According to [3], mud is a complex colloidal system resulted from a surface water treatment process or wastewater treatment, with heterogeneous composition, containing water and particles in suspension, colloids, minerals and organics etc., in which are contained products of metabolic activities and/or raw materials, intermediary products and finished products of some industrial activities. When wastewater goes through treatment plants results besides clean water some technological biphasic muds, considered secondary products, that contain the pollutants eliminated from the wastewater. This thing can represent a major danger for the environment.
It comes from the primary treatment, physic and/or chemical, secondary treatment, biological and tertiary, added to the secondary, many times to remove nutrients.

In the wastewater treatment, with the purpose of removing in the natural receptors or of recirculation, muds are formed that contain the impurities from the raw waters and also the ones from the treatment processes.
The technological schemes applied to the industrial and urban wastewaters, following which muds are resulted, are grouped into two categories: the ones regarding the mechanical-chemical treatment, respectively mechanical-biological treatment. The main sources of sludge from these schemes are presented in figures 1 and 2.

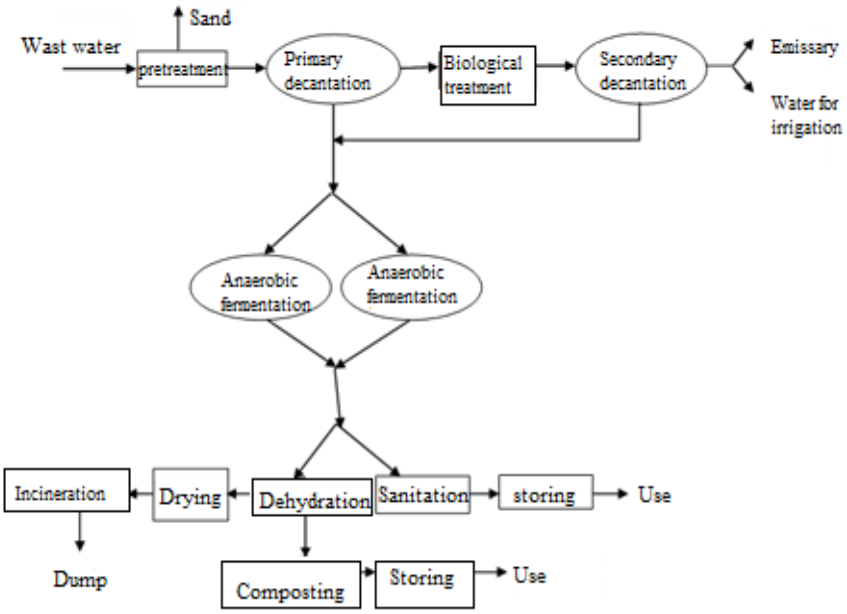

Fig. 1. Sources of sludge from the mechanical-biological treatment plant [4, 5]

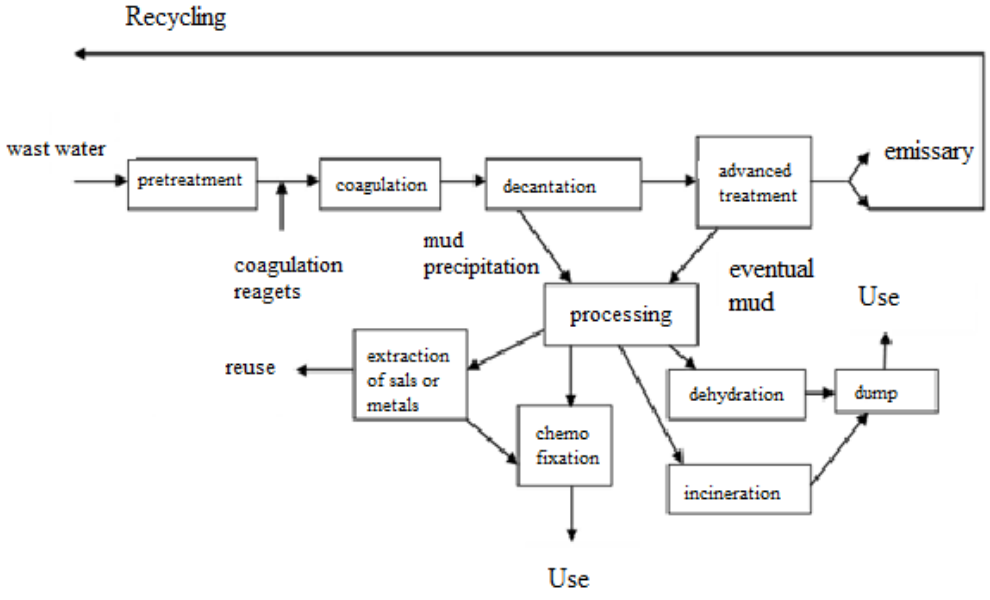

Fig. 2. Sources of sludge from the mechanical-chemical treatment plant [4, 5]

Following this process of water treatment, the main substances that are inducing the pollution are being removed [6]:

- the particles decant naturally or following the physical-chemical treatment
- the excess of micro-organisms that come from the dissolved organic matter
- not biodegradable mineral substances

Those products, together with the water that remained in the treatment basins, forms the mix called sludge.

3. The Elimination and Capitalization of Sewage Sludge from the Perspective of Circular Economy

Sewage sludge, if they respect OM 95/ 2005 and if they are dehydrated (humidity <65%) can be deposited.
The temporary depositing is realized at the generation place of the sludge, from where it is transported to the treatment, elimination and reutilization places. The maximum capacity admitted for the depositing of sludge, that will be treated, is three years, and for the one that is going to be incinerated, one year.
At present, the most used methods and with guaranteed results (figure 3) of eliminating the sludge that comes from the treatment stations, directly into the environment, are the application on the farmland and utilization of compost as fertilizer in horticulture and as nutrient in agriculture [7].

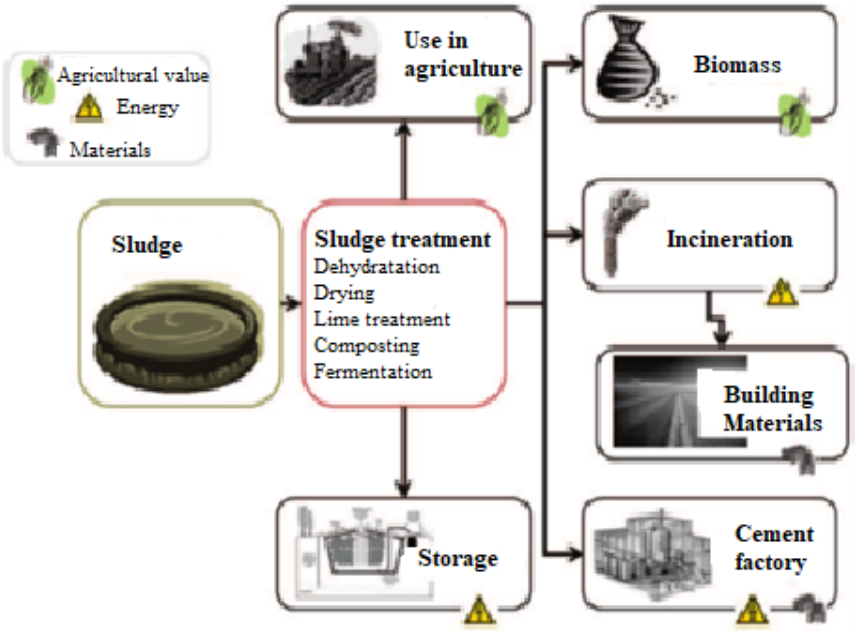

Fig. 3. Ways in which the sludge is finally eliminated [7]

Now, in Romania, around 91% of the resulted sludge is deposited at WTP (Wastewater Treatment Plant), 9% goes into a waste deposit and approximatively 0.2% is utilized in agriculture.
There are more solutions for the elimination and capitalization of the sewage sludge, such as [4, 6]:

- ***Material Capitalization of waste***
  - ✓ Utilization in agriculture, forestry and horticulture;
  - ✓ Making compost;
  - ✓ Degraded soils reconditioning;
  - ✓ Elimination at the waste deposit;
  - ✓ Fabrication of ceramics or aggregates for constructions.
- ***Energetic capitalization:***
  - ✓ Incineration ;
  - ✓ Anaerobic fermentation;
  - ✓ Co-Incineration
  - ✓ Pyrolysis;
  - ✓ Gasification;
  - ✓ Wet Oxidation;
  - ✓ Biofuel Production;
  - ✓ Direct electrical energy production in combustion cells.
- ***The depositing of residual waste*** is applied in the case of ash resulted from the energy capitalization.

The alternatives for the utilization and elimination of sludge from Romania are [4]:

- In agriculture – stabilized mud, preferably dry;
- In forestry – stabilized mud, dry;
- *Land improvements* – stabilized mud, dry;
- *Burning* (cement factories) –drying at WTP or at the cement factory;
- *Energy production* - dry mud , not now;
- *Waste deposits* – stabilized, dry, not now.

As an example of the obtained quantity of mud in a county from Romania, figure 4 shows the sewage sludge production from 2010 until 2018 and expected in 2040 in Harghita County. Overall, the production for the entire county is [8]:

- 2,115 t DS/year in 2010
- 3,862 t DS/year in 2013
- 5, 852 t DS/year in 2018
- 5,300 t DS/year is expected inn 2040.

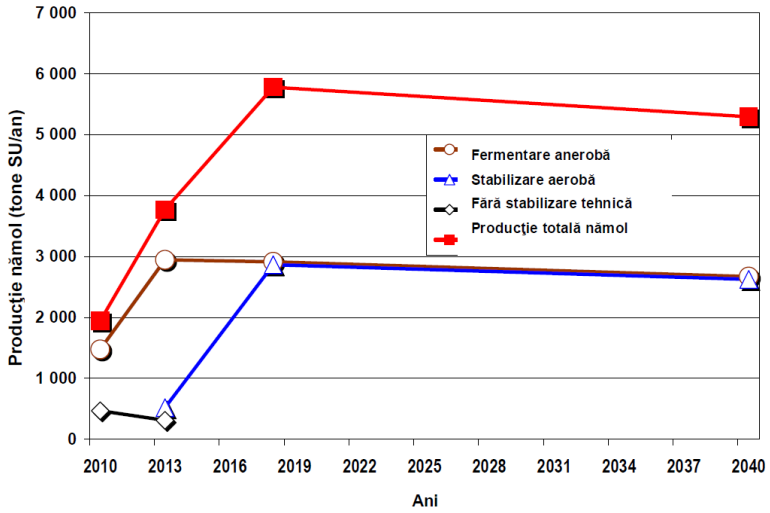

Fig. 4. Sewage sludge production until now and expected in 2040 at the level of Harghita County [8]

3.1 Agricultural Capitalization

Because of its composition, which is rich in nitrogen and phosphorus, sewage sludge can be utilized as a fertilizer for the agricultural soils. Besides its benefits, sewage sludge also contain variable quantities of heavy metals, depending on the industry from which he comes, which, if they exceed the admitted values can become dangerous for the plants but also for the animals and humans. Because of its high content of organic material, sludge can improve clay soils and also the structure of sandy soils.

At European level, there is directive 80/278/EEC, which has as purpose protecting the humans and soils by the pollution with harmful substances that imposes sewage sludge to be treated in advance, making sure that it respects the admitted parameters for heavy metals and other harmful substances. The seven heavy metals that can be toxic for humans and plants are: cadmium, copper, nickel, lead, zinc, mercury and chromium. The maximum allowable quantities are specified in table 1.

Table 1: Maximum allowable values and annual averages of heavy metals added in 10 years [6]

Heavy Metal	Zn	Cu	Ni	Cd	Pb	Hg	Cr
Kg/ha year	15	7.5	3	0.15	15	0.1	15
Romania ppm	2000	500	100	10	300	-	500

In Romania OM no. 49/2004 has been approved, which stipulates the technical environment and soil protection, when sewage sludge is used. The reuse requirements in agriculture are that the mud has to have a drying level of >90% in order not to ferment and to be deposited in silos until usage.
In order to reduce the pollution effect of the mud that is going to be used on the farmlands and for the best capitalization of the nutritive elements, it is mandatory to use adequate treatment processes for the stabilization and for the reduction of the pathogens (table 2) [9].

Table 2: Efficient sludge treatment processes for its utilization in agriculture [10]

Process	Description
Pasteurized mud	Minimum 30 minutes at 70°C or 4 minutes at 55°C followed by mesophilic anaerobic digestion
Mesophilic anaerobic digestion	Primary digestion at least 12 minutes at 35°C or 20 days at 25°C followed by a secondary period of depositing of at least 14 days
Thermophilic anaerobic digestion	Storage period in the digestor of at least 7 days followed by 4 hours at 55°C
Composting	40°C at least 5 days, 4 hours at minimum 55°C inside the reactor, followed by a maturation for the complete reduction of compost
Liquid mud stabilization with lime	Lime is added to increase the pH level at 12 for 12 hours

Mud fertilization value depends, mainly, on the treatment stage, respectively its origin. Unfermented mud contains pathogens and, from this point of view sanitary protection measures must be taken for its use, but has fertilization value bigger than the fermented mud (fermented mud contains 40-50% less nitrogen than fresh mud). After the mud dispersion on the farmlands, those have to be plowed, and their usage being prohibited for plants that their leaves and roots are being consumed raw. From the sanitary point of view, muds dehydrated through thermic treatment and wet oxidation are less dangerous [11].
Used mud can be under different forms [10]:

- liquid;
- mud cakes (25% solid, dry);
- dry mud beads (95% solid, dry).

At a national level, only a few part (4.2%) of the farmlands are suitable for the application of sludge and will use the entire quantity of produced mud. At regional level, differences exist because of topography, types of soils and climate regarding the type of agriculture and the feasibility of mud utilization. This thing assumes that mud can be utilized at maximum in some regions but is restricted in others (especially in NW, Centre and Bucuresti-Ilfov). Variations at county level are more pronounced and in some counties the necessary surface of land for the application of the entire quantity of sludge exceeds the suitable surface (>100%) [12].
Sewage sludge can be also used for energetic plants plantations, like "energy willow Salis viminalis energo" cultivated on large surfaces in Sweden, Poland, Austria and Hungary, because of its fast growth (3-3.5 cm/day) and produces biomass with caloric power superior to beech and oak, approximatively 4900 Kcal/Kg. For its utilization as fertilizer on forest plantations, those muds have to respect the stipulations from Order 344/2004 [4].

3.2. Composting

Composting consists of the sludge mixing with a filling material to obtain a mix that can be aerated in order to realize an accelerated aerobic degradation process. For the aeration of the material, it is necessary a big quantity of energy and the final product must be eliminated on a good quality soil because of the low nutritive composition.
Optimal conditions for composting are: humidity approximatively 50%, carbon-nitrogen report approximatively 25-30, and the temperature 55 °C. For the sludge that results from water treatment the C:N report is very small, of 5-10, and the humidity is very high. For the quantity adjustment dry sawdust can be added with large C:N report, approximatively 500, waste from the garden, forest waste or chopped newspapers.

At sludge composting dry matters should be added that the air flow through the compost layers. For this reason it is usually used a sludge mix of 0.5 m^3 and 75 kg of peat. A much better mix is obtained by adding household waste to the mud, so that humidity is 40-50%. The waste offers the mix a favorable proportion of carbon and nitrogen of around 15:1, offering the missing carbon [11].
Naturally, composting is realized in storage piles, at a temperature of 70^{o}C, during ferment water decreases and the germs are eliminated.
Artificially, composting is realized in a drum stabilizer, in which the mud stays for a day at 120^{o}C. The resulted product is chopped, placed in piles of 1.5m height, left at anaerobic fermentation for a few days and after that used as fertilizer [11].
According to DE 86/278/CEE, composting is realized near ecological waste deposits, thing that cannot be realized in Romania, because it requires large surfaces, machinery and high costs.

3.3. Energy Capitalization

The most used process of energy recovery during the sludge treatment process is anaerobic fermentation (digestion) that has as purpose the extraction of methane, 60-65%, that generates heat, 37-40 ^{o}C and energy, but for a short time, around 6 hours [13].
According to the circular economy's principle, fermented sludge from the biogas tanks can be capitalized through:

- Reutilization on farmlands;
- Co-processing in cement factories;
- Incineration / co-incineration.

If the muds resulted from the treatment of industrial wastewater contain organic compounds and/or inorganic, toxic, that are not allowing the agricultural capitalization, depositing on soil or the application of useful substances recovery procedures, Incineration is being appealed as the only acceptable alternative. During this process, the organic compounds are totally oxidized, and the mineral ones are transformed in metallic oxides. For incineration the prior reduction of raw mud humidity is recommended and also the avoidance of aerobic stabilization or anaerobic fermentation, that diminishes the caloric power of the material that is supposed to be incinerated. Mud preliminary processing should lead to combustion. If the humidity is larger than 50% or the temperature over 750 ^{o}C, additional fuel must be utilized to avoid unpleasant smells.
Incineration has the biggest mud treatment/elimination costs, because of the required fuel and of the air pollution control, made through the gas burning.
The resulted ash is stocked in a waste deposit, and the gas is pre-heated before the evacuation.
In Romania's national energy development strategy, the use of biomass is considered priority. Sadly, in Romania there aren't mud incineration facilities.
Energy recovery from sewage sludge – technologies:
1. Biogas. One of the most efficient, having the possibility to be utilized at electrical energy production, heat, steam etc.
2. Energy from biofuel. Hydrogen is one of the gas fuels recovered from the sewage sludge that in combination with CO^2 forms syngas, an alternative for fossil fuels, in the production of electrical energy and in the production of liquid fuels [13].
3. Microbial combustion cell (MCC). This technology is a solution for the water energetic crisis and for the excessive mud. It can be utilized in order to generate energy on both technological lines, both on the water side, and also on the sludge's one [14].
In Romania there are seven cement factories placed in every region of the country (two in the south region), with the exception of the South-West region and Bucuresti-Ilfov, as it follows [13]:

- Bicaz- Neamț County;
- Medgidia – Constanța County;
- Fieni – Prahova County;
- Câmpulung – Argeș County;
- Deva – Hunedoara County;
- Alesd – Bihor County;
- Hoghiz – Brașov County;

Mud can be utilized as an energy source in cement factories, because the heavy metals that it contains will be blocked in cement, and the large quantity of water from the dehydrated mud has a

minimum effect. The problem of ash inside the factory can be solved with its implementation in cement, without damaging its structural properties.

3.4. Technological Capitalization

Muds and sands resulted from the urban and industrial wastewater treatment plants can be utilized in constructions along with base raw material in order to reduce energy and to produce a material that responds to circular economy's requirements [7].
In addition, it can be capitalized as construction material (bricks and plaster material). To obtain bricks, it is mixed through centrifugation 45% cement with 55% mud, for 15 minutes, until a homogenous paste that is extracted from a form is obtained and is let to dry up for 24 hours. To increase its resistance, after it is extracted from the form, it is let outside for 3-4 days. Final product (figure 5) is considered inert waste, according to the actual environment legislation (Law 211/2011, HG 856/2002, Order 95/2005) [14].

Fig. 5. Brick obtained from mud and cement [14]

3.5. Mud Depositing

The elimination of dangerous waste in ecologic deposits is the last option in every mud management strategy because it is a waste of a very useful resource for fields' fertilization and also for energy recovery; it is also against politics and the legislation for the reduction of biodegradable waste.
Muds that cannot be capitalized must be deposited in appropriate environment protection conditions. For this reason, mud ponds are being used, special storage dumps, underground, discharge into the sea at big distances from the shore and a certain depth.
Sewage sludge is deposited in homogenous deposits (mono-deposits) only for mud, or in mixt deposits together with other municipal deposits.
For homogenous deposits, mud should be hydrated in advance and dried. A perfect correlation should exist between deposit's organization, transport vehicles manipulation and mud manipulation inside the deposit [15].
For mixt deposits, the international norms foresee a mud quantity of 20-25% out of the deposited waste, while national norms limit this ratio to 10%. To be able to deposit the mud a bed of approximatively 3m of solid waste is required, while the layers should be alternated. Romanian legislation foresees a content of at least 35% solid substance [15].

4. Conclusions

As the population grows and the industry develops, an imbalance is being created between human and environment, thing that generates major and irreversible implications from an ecologic point of view and great economic implications with very important financial losses.
Depositing, recycling or utilizing such materials represents a difficult problem mainly for large urban agglomerations. In the developed European countries, sewage sludge resulted from wastewater treatment plants is processed with the help of the most evolved technologies and machinery, so as it can be utilized as organic fertilizer and for soils restoration.

If those muds go through a well-defined cycle: formation, stabilization, dehydration and complete removal from the circuit, are no longer listed as waste. The final process is obtained through three methods: incineration, stocking in special deposits and utilization as organic fertilizer.
Choosing the capitalization/elimination method has to take in consideration the impact on environment and the farmers' acceptance (for utilization in agriculture). The knowledge regarding the optimal deployment conditions of the processes is absolutely necessary, being able to decrease the presented disadvantages using the mud processing and elimination methods.
Every capitalization solution presented in this paper has advantages and disadvantages, but there is the possibility to apply some alternative methods, depending on the activity and area particularities.

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