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# Sewage sludge from wastewater treatment as a new renewable resource

MINIREVIEW

Module G01– Renewable resources

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## 0. Abstract

The following minireview is based on analyzing the sustainability of three viable energy recovery techniques that have different approaches: anaerobic digestion, pyrolysis, and gasification.

## 1. Introduction

In the 20$^{th}$ century, the accelerating growth of big urban centre due to overpopulation, industrialization, and excessive consumerism has caused higher demands for finite resources such as water, land space, food, and energy. In the same line, pollution and waste management issues have also been intensified. Both problems are regarded as detrimental to sustainable development, but the growth of sustainable strategies for production, waste management, and energy utilization has ignited attention [1,2].

Nowadays, there are different types of waste management like the wastewater treatment plant (WWTP). In this process, water can be sourced from commercial, municipal, or industrial processes, but regardless of its origin, two streams for different purposes are produced: a stream that contains treated wastewater, and another one that contains separated sludge from wastewater [3,2]. Related to the aforementioned waste management, this has become more efficient with the implementation of new processes in the last 30 years, increasing the quality of treated wastewater, and at the same time, an increasement of unwanted pollutants, like heavy metals, transferred into the sludge phase [3].

Sewage sludge is an unavoidable by-product obtained during WWTP, which is increasing with the progressive expansion of wastewater networks. In Europe, the global production has been estimated at 10 million tons per year of sewage sludge dry matter [3,4]. Notwithstanding the highest presence of unwanted polluting trace contaminants, sludge should not be classified as undesirable waste because is a renewable, and potentially valuable resource due to its two main components that are technically and economically recoverable: nutrients and energy. All mentioned characteristics classify sewage sludge as a by-product that fulfills the circular economy concept, suiting for energy production with different methods and processes [1,3,4]. Apart from its use for energy recovery, the most predominant use of sewage sludge is for agricultural uses, like fertilizers [2]. The main advantages of the agricultural application are the inexpensive price and the logical way of eco-cycling nutrients in the soil. Even so, sewage sludge in the agriculture field is decreasing because some studies demonstrated the high concentration of heavy metals, harmful to the food chain, and the concerning emissions of organic pollutants [3,5].

## 2. Types of sewage sludge

Sewage sludge is described as a liquid, semi-solid, or solid heterogeneous mixture generated during the WWTP. It is classified as nutrient-rich organic material, where about 60 % comes from the sewers and up to 40% originated from the microorganisms, or biomass, which grows during the treatment process [2,3]. About the percentage coming from sewers, sewage sludge is composed of undigested organics, like plant residues, oils, paper, fecal material, moisture, and inorganic materials. Specifically, this portion is composed of proteins and peptides, polysaccharides, lipids, plant macromolecules with phenolic structures, like lignin, or aliphatic structures such as suberin. This is along with micro-pollutants such as dibenzofurans and polycyclic aromatic hydrocarbons (PAH) are also present [6].

During the wastewater treatment, the composition of sludge varies (Table 1). For this reason, sludge is mainly classified as raw and activated sludge.

*Raw sludge (RS)*

Raw sludge, also known as primary sludge, is a flocculated mixture of inorganic and organic matter with gas bubbles trapped within the suspension. This product is generated because of primary clarification during WWTP that consists of mechanical processes (screening, grit removal, sedimentation) for removing suspended soils, grease, and oil. It usually contains about 93-99.5 % of water, and a high ratio of suspended and dissolved organic matter that is easily degradable [5]–[8]. Besides, the bacteria in RS are considered to be held together through hydrogen bonds and non-specified Lif-shitz van der Waals forces [7].

*Activated sludge (AS)*

Activated sludge is also called secondary sludge. It is generated as a product of the secondary treatment process where is removed approximately 85 % of the organic matter by using bacteria in it. This step based on biological treatment contains mainly polysaccharide and protein-rich bacteria and microbial cells that form extracellular polymeric substances (EPS). The EPS forms a structure with a negative surface charge and behaves like a gel when interacts with water and forms flocs. Besides, it has been stated that structure is held together by hydrogen and electrostatic bonds [7,8].

Table 1. General composition of primary and activated sludge. Table modified and taken from [6].

| Parameters | Primary sludge | Activated sludge | Composition |
|---|---|---|---|
| Total dry solids (TS) | 5-9 | 0.8-12 | In common:<br>-Presence of toxic pollutants: heavy metals (<1 mg/L -1000 mg/L), PCB, PAH, pesticides.<br>-Pathogens and microbial pollutants.<br>-Water varies from low percentage to more than 95 %. |
| Volatile solids (% TS) | 60-80 | 59-68 | |
| Nitrogen (% TS) | 1.5-4 | 2.4-5.0 | |
| Phosphorus (%TS) | 0.8-2.8 | 0.5-0,7 | |
| pH | 5-8 | 6.5-8 | |
| Grease and fats (%TS) | 7-35 | 5-12 | |
| Proteins (%TS) | 20-30 | 32-41 | |
| Heat value (MJ/kg) | 17-18 | 14-16 | |

The potential use of sludge for energy recovery is function with its composition, which is considered a mixture of inorganic matter (inert material), organic volatile matter, and water. The energy content of sludge exclusively lies in the quantity of the volatile solid [6].

## 3. Treatments for Energy production

In the European Union, the final disposal of sludge mainly includes agricultural use (42.4 %), incineration (26.9 %), landfilling (13.6 %), and others like long-term storage or composting (17.1 %) [4]. Nowadays, due to strict environmental regulations and the interest in a circular economy, disposal techniques such as composting, landfilling or storage are considered unsustainable because of the scarcity of land to dump it and health concerns produced to the composition of sludge (heavy metals, organic pollutants, or pathogens) in the agricultural field. Although its most predominant use it as fertilizer, due to the restrictions caused by high phosphoric, organic and heavy metal content, the requirements for biological routes such as anaerobic digestion, thermal reactors for treatment, stabilization, and subsequent processing of sludge to any resource or energy recovery use have increased [2]. This section will consist of a brief explanation of techniques used for energy recovery, mentioning inputs and outputs involved during the process (Image 1).

*Anaerobic digestion*

Anaerobic digestion (AD) is considered the preferred stabilization method due to the production of biogas which is a valuable energy source. In the European frameworks, 16.1 million tonnes of biogas has been produced in 2016, where sewage sludge feedstock contributed 8.7 % of the total amount. The application of AD to generate biogas from activated sludge can assist in the development of a circular economy and can partially replace fossil fuels [1,4].

The operation must take place under restrictive anaerobic conditions using microorganisms. This process is formed by three main steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. These stages have the purpose of reducing the mass and volume of the sludge while the organics are converted into a mixture of methane (60-65 %), and carbon dioxide (35-40 %) [3,9]. However, some impurities will be formed like $H_2S$ and water which will be removed whilst the resulting biogas is going to be used in combined heat and power systems (CHP) or boilers - calorific value about 28.03–38.92 $MJ/m^3$ [3,4]. In relation to the stages, hydrolysis involves a conversion from non-toxic organics to sugars, lipids, and proteins. Then, acetogenesis and acidogenesis aid the fermentation of the hydrolysis products into $CO_2$, acetate, and hydrogen gas, which are converted to methane through the last step [2].

AD has ignited attention because it can convert 30-60% of organic compounds into biomass with a lack of drying requirements, but takes a long reaction time, ranging between 7 days to 5 weeks. The product formed is generated for many purposes like electricity and heat generation and for this reason, it is considered a sustainable technology for managing sewage sludge. However, the conversion efficiency is lower and the aim of reducing emissions with biogas production and at the same time, improving the yield of biogas requires additional energy input. In addition, the presence of the considerable amount of heavy metals could induce the inhibition of the digestion process [1,2,10].

*Pyrolysis*

This technique takes part in thermal treatment which also includes incineration and gasification. These treatments have gained attention for reduction of the volume, energy and fuel provision, and destruction of pathogens present in the sludge. In the aforementioned treatment, the thermal drying step is mandatory to reduce the moisture content due to a decrease the energy input [10].

The pyrolysis process consists of thermal decomposition with a non-oxygenated atmosphere. The process is usually operated at moderate temperatures (350-600 ºC), although some reactors operate at temperatures up to 900 ºC. The output product depends on the process temperature where char yield decreases when temperature increases [2,10]. This technique can convert different types of sewage sludge (raw and activated) into a gas (syngas) and usable oil (bio-oil). Syngas includes CO, $H_2$, $CO_2$, $CH_4$, and other hydrocarbons and condensable compounds. Besides, biochar is formed as a by-product, which is regarded as carbonaceous residues capable of immobilizing heavy metals [4,10].

Notwithstanding the advantages like immobilization of heavy metals in the carbonaceous residue, notable reduction of volume and toxic organic compounds, excellent energy recovery, and the option of using bio-oil to provide chemicals (fertilizers, resins…), this process is considered a high-cost option because the use of char as heavy metals disposal requires expensive downstream. Moreover, pyrolysis does not comply with permitted levels of undesired emissions. This last point is bounded by the temperature factor because increasing it, can lead to $NO_x$ and $SO_X$ precursors which are considered non-desired pollutants [10].

*Gasification*

The gasification technique is the incomplete oxidation of biodegradable materials in high temperatures, ranging from 800-1000 ºC, and an oxidant and restricted atmosphere, which can be composed by using carbon dioxide, oxygen, steam, or mixtures of the aforementioned gases. By the increasement of the temperature, the gasification reaction is divided into four sub-sections, being drying of the sample at 70-200ºC, devolatilization ranging from 350-600ºC, and finally, oxidation of volatiles, and char gasification [2][11]. The main outputs from this process are flammable gases like hydrogen, monoxide carbon, methane, and ashes. Related to the feedstock, this process is tolerant with diverse and contaminated feedstocks like sewage sludge.

The main advantages of the output gases are based on their use for electricity, heating generation, or liquid fuel synthesis. The use is justified by the calorific value of the syngas ranging about 4-12 MJ/m$^3$. Apart from this point, sludge gasification is related to ash issues due to the elevated presence of inorganic constituents like heavy metals, which at high temperatures (>750 ºC) results in deposition [2].

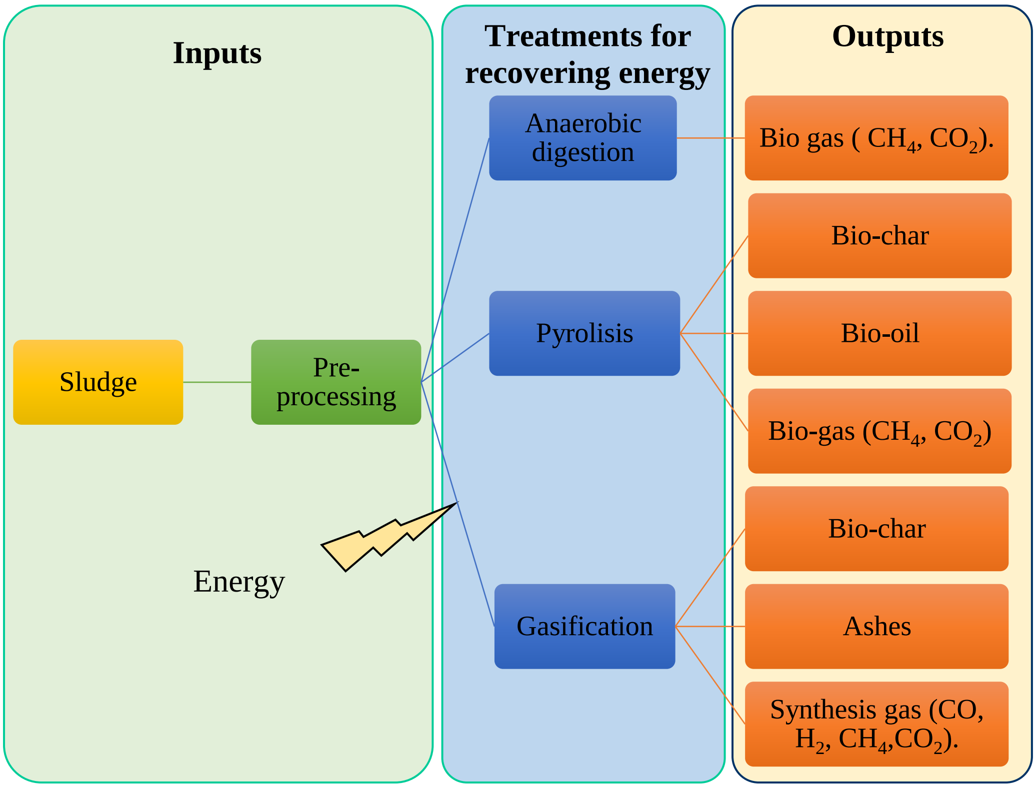


Figure 1. Inputs and outputs of treatments for recovery energy

## 4. Conclusions

As discussed throughout this review, the techniques analyzed have disadvantages that limit their application in the industry. About the anaerobic digestion treatment, the long reaction time and the low conversion efficiency are some of the disadvantages of this treatment. Compared to technical treatment processes, they require energy-intensive drying, a disposal or reuse strategy for the by-products formed, and emission control, which increases its operational cost. From an objective point of view, the most sustainable technique is anaerobic digestion because by-products that need strategic treatment are not formed such as biochar.

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