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CIRCULAR ECONOMY IN WASTEWATER TREATMENT PLANT

Katarzyna KALEMBA *

* PhD; Department of Water Protection, Central Mining Institute, plac Gwarków 1, 40-166, Katowice, Poland
E-mail address: *kkalemba@gig.eu*

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Abstract
Wastewater treatment plants are becoming an important part of circular economy. In addition to the classic role of wastewater treatment plants, they are gaining a new important mission to fulfil. According to the Nutrients-Energy-Water (N-E-W) paradigm, wastewater treatment plants should also focus on energy production and resource recovery. Intensification of biogas production is an important element in improving the energy efficiency of wastewater treatment plants. This can be achieved by introducing sewage sludge co-digestion with organic substrate, thermal hydrolysis and disintegration of the sludge. Water renewal, which includes a number of processes to restore the water features of the wastewater, is also becoming an important objective. Intensive research is being carried out on the production of bioplastics by bacteria inhabiting municipal and industrial sewage. Technologies for recovery of nutrients (nitrogen and phosphorus) from sewage and sludge are also advanced. The paper presents current trends in the development of sewage treatment plants based on the assumptions of circular economy and current policy of the European Green Deal.

Keywords: **Biogas production; Circular economy; N-E-W paradigm; Resource recovery; WWTP.**

1. SUSTAINABLE DEVELOPMENT IN LINE WITH THE IDEA OF A CIRCULAR ECONOMY

Faced with a depleting natural resources and a high waste production in 2015 the European Commission issued the statement of the European Union (EU) action plan for a circular economy – “Closing the loop” [1]. The main assumption of this document is to create an economy in which resources will be used in a more sustainable way. This will contribute to energy savings and minimize the damage caused by the use of resources at a level that exceeds the Earth’s capacity to renew them. An important issue highlighted in the Commission document is waste management, which focuses on unlocking its potential. This approach allows waste to be treated as a valuable material that returns to the economy, thus contributing to the development of the secondary raw materials market.

The idea of circular management is inconsistent with the N-E-W paradigm, which has been successively introduced to water and sewage management and with the strategy of dealing with municipal sewage sludge for several years. Both concepts combine common objectives such as sustainability, prevention of climate change and progressive water eutrophication. The basic principle behind both concepts is the resource saving, recovery and use of renewable energy [2].

Transforming our world: The 2030 Agenda for Sustainable Development, adopted in 2015 by 193 United Nations (UN) countries, is the action programme with an unprecedented scope and importance of defining a sustainable development model at global level. The Agenda identifies 17 Sustainable Development Goals and related 169 targets to be achieved globally by the year 2030. They concern achievements in 5 areas (called 5xP): people, planet, prosperity, peace and partnership. The planet area aims to build a development model that will foster economic growth, greater social inclusion and make rational use of environmental resources, resulting in a better quality of life and the resolution of poverty [3].

The European Green Deal, which was presented first time in the year 2019 by the European Commission is a package of measures to enable citizens and businesses to benefit from a sustainable green transformation. The plan includes cutting emissions, investing in innovative research and innovation and also protecting the environment. The main goal of Green Deal is making Europe climate neutral in the year 2050 by moving to a circular economy, combating biodiversity loss and reducing pollution [4].

2. THE N-E-W (NUTRIENTS-ENERGY-WATER) PARADIGM

The idea of the N-E-W paradigm was created in the USA by the National Association of Clean Water Agencies, Federation of Water Environment and Water Environment Research Foundation [5] in 2012 and presented by the Working Group of the Water Environment Federation [6] in 2014. It was a response to the ongoing climate and demographic changes and increasing water pollution.

This paradigm represents a new, holistic approach to wastewater treatment and sludge treatment processes, which change the overall objectives of the wastewater treatment plant operation. According to the current EU water policy [7], the primary duty of the sewage treatment plant was to protect the water environment. Nowadays, the plant must go beyond the traditional approach and focus not only on environmental, but also social and economic aspects (Fig. 1).

3. INTENSIFICATION OF BIOGAS PRODUCTION

3.1. Co-digestion

The development of strategies to improve energy efficiency in current and new wastewater treatment plants is a key aspect due to the high energy intensity of the technological processes conducted there.

Currently, it is considered economically beneficial to intensify biogas production by co-digestion of sludge with organic substrate. This solution allows for not only reducing the cost of purchasing electricity, which directly affects the unit cost of wastewater treatment, but also the partial energy independence of the facility. Co-digestion requires prior determination of the appropriate nutrient proportions, especially with regard to the correct C/N (carbon to nitrogen) ratio. This minimizes the possibility of nutrient deficiencies and prevents inhibition of the fermentation process. The assessment of the suitability of the waste for the process is based on the biogas potential.

The combination of substances fitted to co-digestion with sewage sludge should have a higher biogas potential than only sludge and also should be marked by absence of toxic substances and pathogens. Before entering the digester, substrates must be pre-treated, e.g. pasteurised, averaged, macerated, homogenised. An important criterion for the selection of substrates for co-digestion is availability on the local market. Locally available waste reduces the costs associated with transporting the raw material and storing it [8, 9].

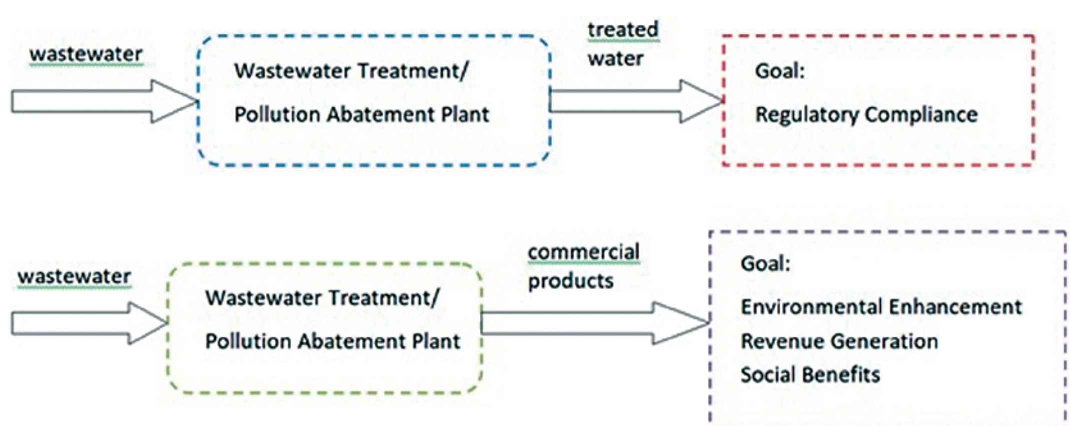

Figure 1.
Conventional wastewater treatment plant (WWTP) and N-E-W resource recovery facilities (after [6])

3.2. Sludge thermal hydrolysis

A thermal conditioning of a sewage sludge (thermal disintegration) leads directly to the destruction of microbial cells, acceleration of the hydrolysis process and increased susceptibility of sludge to fermentation. Pre-treated sludge in later stages of processing is more susceptible to dewatering, while the high temperature of the process ensure sludge. By rising the density of the sludge fed to the digesters, the load on the sludge is increased. A more efficient fermentation process also increases rate of biogas production and the degree of decomposition. A wastewater treatment plant equipped with cogeneration units increases the production of electricity and reduces the amount of sludge sent for further processing. Additionally, thermal hydrolysis process reduces odour and pathogen regrowth from dewatering and minimizes inhibition due to hydrogen sulphide [10, 11]. Thermal hydrolysis technologies like Cambi, Biothelys, Exelys are the most spread technologies used to improve anaerobic digestion in WWTPs.

3.3. Mechanical disintegration methods

Mechanical disruption of sewage sludge has gained acceptance due to its various successful industrial scale applications. High-pressure homogenization (HPH) is a well known mechanical method for cell disruption. HPH was mainly developed for the stabilization of food and dairy emulsions. Recently, HPH has been reported as a sludge pretreatment method, which changes both the rate and extent of sewage sludge degradation in anaerobic digestion processes. HPH works on the principle of external shear, cavitation, pressure gradient and turbulence [12, 13].

An interesting method of intensifying biogas production is the ultrasonic disintegration of sewage sludge directed to the fermentation process. The disintegration consists in introducing energy into the sludge, which is to weaken and destroy cell membranes of microorganisms in the sludge. In this way, enzymes and substances needed for the decomposition of organic matter during biological stabilization are released into the sludge liquid. Lysing and oxidation of the cell walls of microorganisms contributes to the intensification of hydrolysis. Sludge disintegration is environmentally safe, with no hazardous waste or harmful chemical compounds for the environment, so the application of these disintegration methods was constantly growing in recent decades [14, 15].

4. RESOURCE RECOVERY

4.1. Water renewal

It is expected that 5.5 billion people (2/3 of the population) will live in an areas exposed to water stress by 2025. This means that the amount of renewable water resources (Falkenmark index) per person per year will be less than 1700 m^3. Approximately 1.8 billion people will live in areas with significant water stress (Falkenmark index <1000 m^3 per person per year) [16]. The reuse of wastewater will become an important alternative to traditional water sources in the face of dwindling water resources and prolonged droughts. Water renewal is based on a number of treatment processes that restore the water's functional properties. Renewed water can be used for consumption purposes (feeding drinking water circuits with highly purified wastewater) or for non-consumption purposes, which includes other uses. Two types of wastewater reuse can be distinguished: direct wastewater reuse, where the treatment and reception systems are combined, and indirect wastewater reuse, which involves the processes of mixing and diluting the reconditioned wastewater, prior to its use, in natural surface water and groundwater [17]. Mechanically, biologically and chemically treated wastewater may contain organic micro pollutants, toxic inorganic compounds, biogenic compounds, dissolved mineral compounds. Some organic and inorganic compounds will not undergo biological decomposition (refractive compounds). Non-biological methods are used for their removal, e.g. filtration, coagulation, adsorption, distillation, extraction, ion exchange, membrane processes [18]. The aim is now to maximise the use of membrane techniques that can ensure adequate removal of undesirable substances (ultrafiltartion (UF), reverse osmosis (RO), electrodeionization (EDI), electrodialysis reversal (EDR)).

4.2. Bioplastic

Polyhydroxyalkanoates (PHA) are polymers synthesized by microorganisms or obtained by means of genetically modified bacteria. PHA is in the form of granules found in the bacterial cytoplasm. These granules are a backup material that is used by micro-organisms in the absence of nutrients such as nitrogen, phosphorus and sulphur, while there is an excess of carbon sources. Polyhydroxyalkanoates have similar material properties to polypropylene, but are biodegradable and produced from renewable resources [19, 20, 21].

Due to the high costs of PHA production with the use of pure microbial cultures, an ecological and cost-reducing solution is to obtain PHA from active sludge. This gives the possibility to use, as raw materials, by-products of the wastewater treatment process. In the first stage, wastewater is treated with the classic method based on the use of activated sludge. The wastewater treatment process ends in a secondary settling tank, where the treated wastewater is separated from suspended activated sludge. Part of the sludge is recirculated to biological reactors, while the excess is removed from the system and directed to the technological part responsible for the PHA production process. In a reactor for the production of PHA, the following actions are crucial: optimization of process conditions, i.e. acclimatization of sludge or enrichment with microorganisms accumulating PHA and dosing of carbon substrates (e.g. acetates) into the reactor. The application of active sludge treated with alternating anaerobic conditions brings very good results. Biosynthesis of PHA in the cells of microorganisms is stimulated by the variability of aerobic conditions or a reduction in the content of biogenic elements (nitrogen and phosphorus) with an excess of organic carbon [22].

4.3. Biogenic compounds

The recovery of ammonium nitrogen from fermentation leachate can be carried out by biological or physico-chemical methods or as a combination of both of them. In most cases, the recovery of nitrogen and phosphorus can be simultaneous and then the struvite precipitation method is used. Struvite is a rare mineral in nature. Chemically, it is hydrated magnesium ammonium phosphate with the formula $MgNH_4PO_4 \times 6H_2O$. Despite its low water solubility, struvite is a source of phosphorus, nitrogen and magnesium for plants. It is the most beneficial form of phosphorus, bioavailable to plants, because the fertilizing components are released slowly. This reduces the need for frequent fertilization. Processes occurring in the environment (biological nitrification) release nutrients from the struvite in a controlled way at regular intervals. Therefore, struvite of appropriate granulation can be applied to the soil in doses much higher than conventional fertilizers without fear of overdosing. The process of struvite precipitation can be controlled and optimized to obtain the lowest concentrations of nitrogen and phosphorus in the reactor drain [23, 24]. The following struvite recovery technologies are used worldwide: DHV Crystalactor®, Unitika Phosnix®, StruviaTM, Linak®, Hielscher, Ostara PEARL®, NuReSys®, Multiform HarvestTM.

5. SUMMARY

The transformation from linear economy to circular economy is the result of a change the approach to natural resources, recycled materials and wastes. Wastewater treatment plants become an important element of this transformation because they are a place where this model assumption can be effectively implemented. In accordance with the N-E-W paradigm, activities related to innovative technologies for recovering organic compounds from process streams, closing water and wastewater cycle or implementing solutions aimed at optimising energy consumption are introduced in wastewater treatment plants.

An important element of improving the energy efficiency of a wastewater treatment plant is the introduction of processes aimed at intensifying biogas production. This can be achieved by introducing additional substrates into the digesters and using methods of sludge disintegration. When considering wastewater treatment plants as a place of source renewal, special attention should be paid to the water renewal process. In addition to the well-known and increasingly common methods of nitrogen and phosphorus recovery, research on the recovery of bioplastics is becoming increasingly popular.

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