Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726), 11(X), 2023:
http://dx.doi.org/10.7770/safer-V11N1-art614

Sustainable resource recovery from municipal wastewater: An overview.

Recuperación sostenible de recursos de aguas residuales municipales: una visión general

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ABSTRACT

The rapid growth of human population, climate change and economic growth has resulted in a greater demand for natural resources includes water, nutrients and energy which leads to huge production of municipal wastewater. It ultimately puts pressure on the environment as it leads to the water pollution. The traditional methods used for municipal wastewater treatment for removal of contaminants are effective in human health protection, however, needs large amount of energy and materials for the removal of contaminants and are inefficient for the recovery of resources. To overcome this, sustainable approach for resource recovery from municipal wastewater is the best alternative as wastewater contains abundant crucial resources such as water, organic and inorganic material. If it is recovered and recycled, leads to reduce the stress on natural resources. This paper discussed an overview on recovery of different resources such as biogas, biohydrogen, single cell proteins, water, metals, nutrients, fertilizers and Polyhydroxyalkanoate from municipal wastewater which can help to reduce pressure on natural resources, pollution and help to increase circular economy, which leads to the sustain the environment.

Key words: Energy recovery, nutrient recovery, sustainable resource recovery.

RESUMEN

El rápido crecimiento de la población humana, el cambio climático y el crecimiento económico han resultado en una mayor demanda de recursos naturales que incluye agua, nutrientes y energía, lo que conduce a una enorme producción de aguas residuales municipales. En última instancia, ejerce presión sobre el medio ambiente ya que conduce a la contaminación del agua. Los métodos tradicionales utilizados para el tratamiento de aguas residuales municipales para la eliminación de contaminantes son eficaces en la protección de la salud humana, sin embargo, necesitan una gran cantidad de energía y materiales para la eliminación de contaminantes y son ineficientes para la recuperación de recursos. Para superar esto, un enfoque sostenible para la recuperación de recursos de las aguas residuales municipales es la mejor alternativa, ya que las aguas residuales contienen abundantes recursos cruciales como agua y material orgánico e inorgánico. Si se recupera y recicla, se reduce el estrés sobre los recursos naturales. Este documento analiza una visión general sobre la recuperación de diferentes recursos como biogás, biohidrógeno, proteínas unicelulares, agua, metales, nutrientes, fertilizantes y polihidroxialcanoato de aguas residuales municipales, que pueden ayudar a reducir la presión sobre los recursos naturales, la contaminación y ayudar a aumentar la economía circular. lo que lleva al sostenimiento del medio ambiente.

Palabras clave: Recuperación energética, recuperación de nutrientes, recuperación sostenible de recursos.

INTRODUCTION

In recent years, the rapid increase in urbanization, industrialization and population, leads to high demands of water and other resources. After use, these materials become part of waste material which goes into the nearby water bodies and results in the production of municipal wastewater. Because of this, water resource is shrinking, which leads to water scarcity (Zarei, 2020). Approximately 70% of water is available on the earth's surface. However, only 2% of it is freshwater whereas rest of the water is inaccessible for human consumption (Prakash et al., 2018: Sonune and Garode, 2018). The conventional processes could remove contaminants from wastewater effectively, however they are cost intensive because of high energy consumption, fuel and chemicals. Also, it cannot recirculate materials from waste.

Demands for basic needs such as water, food, and energy sources such as fuel and electricity are increased as a rise in population. Fossil fuels such as diesel, crude oil, coal, gasoline and natural gas are used mostly since the global revolution started. The excessive use of fossil fuels is adversely affecting environmental quality includes air pollution, global warming, greenhouse gas emissions, acid rain, smog, and climate change (Nanda and Berruti, 2021). In order to overcome this issue, sustainable resource recovery is receiving more attention these days as it recirculates the resources from municipal wastewater (Meena et al., 2019). Wastewater contains a high concentration of nutrients, organic and inorganic materials as well as energy (Sonune, 2021; Rene et al., 2020; Jodar-Abellan et al., 2019). The energy and resource recovery from the wastewater enhance notable value streams, improve water quality and cost recovery. Many resources can be recovered from municipal wastewater which ultimately contributes to the sustainable development that is aim of the universe. Efficient resource recovery and reuse of wastewater can generate a sustainable source of revenue, supports green economy and improves environmental health (Zarei, 2020). The present paper discussed an overview on recovery of different resource such as biogas, biohydrogen, single cell proteins, water, metals, nutrients, fertilizers and Polyhydroxyalkanoate from municipal wastewater.

Resource recovery from municipal wastewater

Municipal wastewater contains many resources such as biogas, biohydrogen, single cell proteins, water, metals, nutrients, fertilizers and Polyhydroxyalkanoate which can be recovered and recycled (Fig.1).

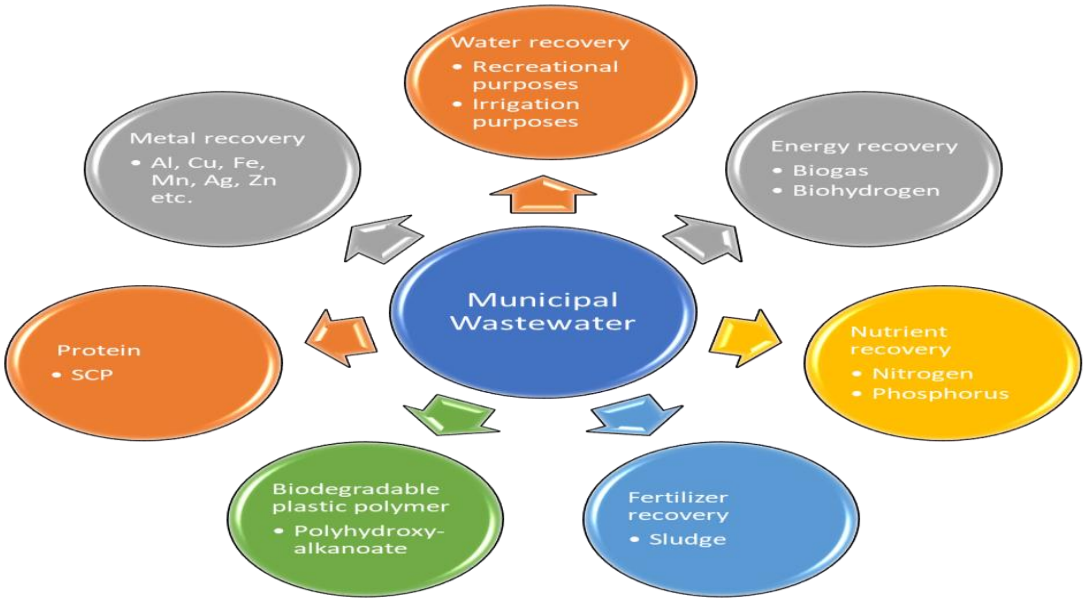

Fig.1: Municipal wastewater resources

2.1 Biogas

Presently, the well-known and most widely used method for the recovery of energy is an anaerobic digestion process and highly recommended as environmentally friendly and cost-effective technology for biogas production from wastewater resources. The sludge from wastewater undergoes transformation into biogas. Biogas is composed of methane (55%–75%), carbon dioxide (25%–45%), nitrogen (0–5%), hydrogen (0–1%) along with the traces amount of other gases (Demirbas et al., 2016). Biogas production from organic materials presents in municipal wastewater through the anaerobic digestion is an important source of electric power and heat energy generation (Rezaee et al., 2020). Actually, it is a transformation of chemical energy of organic substances through the anaerobic digestion into the heat energy and electric energy under anaerobic conditions with the help of microorganism. The main component of sewage sludge includes mainly carbohydrates, lipids and proteins. It also contains hazardous and toxic organic and inorganic contaminants. The biogas production process occurs in four main phases such as hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Elalami et al., 2019). In hydrolysis, the complex macromolecules are converted into simple monomers by hydrolytic enzymes producing microorganisms includes genera of *Cellulomonas, Bacillus, Streptomyces, Microbispora, Clostridium, Thermomonospora, Erwinia* and *Ruminococcus* (Nanda and Berruti, 2021). In the second phage, acidogenic microorganisms convert simple monomers into volatile fatty acids, alcohols, carbon dioxide and hydrogen. In the third phase, substrate produced in the second phase is mainly converted into acetic acid by acetogenic microbes. The acidogenesis and acetogenesis microorganisms include genera of *Clostridium, Acetobacterium, Ruminococcus, Eubacterium* and *Sporomusa* (Jain et al., 2015). In final phage, methanogenic microbes convert acetic acid, hydrogen and carbon dioxide into biogas. Methanogenic microorganisms include genera of *Methanococcus, Methanobrevibacter, Methanobacterium, Methanocorpusculum,* *Methanomicrobium, Methanoculleus, Methanosarcina* and *Methanogenium* (Rusmanis et al., 2019; Wainaina et al., 2020). In the recent year, population growth and high demands for energy-based resources, biogas is a valuable substitute. It provides a sustainable option for providing renewable materials and fuels thereby contributing to circular economy (Antoniou et al., 2019).

2.2 Biohydrogen

Because of the environmental issues, including GHGs emissions and increasing prices of fossil fuels, sustainable and renewable sources of energy such as hydrogen are increased. During combustion, hydrogen does not produce CO2, has high energy content as well as one of the most eco-friendly energy resources. Many processes have been developed for hydrogen production, however the leading processes are depends on the use fossil fuels that are energy intensive and have a high carbon footprint (Dincer and Acar, 2015; Puyol et al., 2017). The alternative source for hydrogen production is sewage which can prevent carbonisation of the energy system and help to sustain the environment. Sewage sludge, industrial waste, as well as agricultural waste are the raw material used for biohydrogen production by a biological process. In biological process, photo or dark fermentation can be applied to produce hydrogen from wastewater. Many reports suggest that, dark fermentation is the most efficient process for hydrogen production over other processes (Preethi, 2019; Sharma et al., 2020). In dark fermentation, pre-treatment of the substrate or inoculum is employed to enhance the hydrogen production. It improves the activity of hydrogen producing microorganisms while suppress the activity of methanogens. However, the efficient hydrogen productions were influenced by several factors such as nutrient availability, substrate composition, bacterial consortium and mode and operation of reactors (Wainaina et al., 2020).

2.3 Nutrients

Eutrophication is one of the major environmental issues. This can be avoided by removal of excess nutrient from the wastewater so that water may be reuse and is the best option to sustain the environment. Eutrophication process causes numerous effects on the aquatic ecosystem such as deterioration of water quality, depletion of dissolved oxygen level, endangers fishing and degradation of recreational opportunities. There are many studies that showed reduction in the concentration of the nutrient by biological and physiochemical process (Al-Ghouti et al., 2019; Meena et al., 2019).

The major nutrients responsible for eutrophication are nitrogen and phosphorus. In biological nitrogen removal process, ammonia, nitrate and nitrite are oxidized by autotrophic microorganisms. The complete removal of nitrogen could be achieved by combining biological nitrification and denitrification process. Several processes are available for removal of nitrogen includes conventional nitrification and denitrification, SHARON, anammox, OLAND and CANON (Jenicek et al., 2004, Meena et al., 2019). Phosphorus is an important element for all living organisms. Hence, phosphorous recovery from waste material that contain phosphorous is of great significance (Petzet et al., 2011). Removal of phosphorous from the wastewater can be achieved by several processes like chemical precipitation, sedimentation, biological methods and membrane filtration process. However, biological method is cost-effective, produce a less amount of sludge as compared with other processes and easy to operate (Banu et al., 2008).

2.4 Fertilizers

Because of increasing populations, agricultural land is reducing and used for industrialization. It puts pressure to increase in food demand leads to high stress on more crop production. Hence, to meet these demands, excessive use of chemical fertilizers and pesticides have been applied. However, the excess application of such fertilizers has led to the deterioration of the soil equilibrium as well as flora and fauna. To avoid this, alternative sustainable fertilization is needed, which can minimal environmental problems (Chojnacka et al., 2020). Hence, application of sludge from wastewater is best option to solve this problem. After treatment of wastewater, the production of significant amounts of sludge occurs that can be used as a biofertilizer for agriculture, as it contains organic as well as inorganic materials. The organic material acts as a source of nutrient such as carbon, nitrogen etc. to the crop plants. Similarly, several metals as part of inorganic material stimulate or required for growth of plants. Treated sludge improves soil fertility, increases water holding capacity and may reduce the soil erosion by changing physical and chemical properties of soil (Chew et al., 2019).

2.5 Water

Traditionally, the major goal of wastewater treatment has been to convert wastewater into water that is safe to discharge into nearby water bodies without endangering human health and the environment. Because of rapid growth of population and urbanization, scarcity of water is becoming serious problems (Theregowda et al., 2019). Currently, the majority of treated municipal wastewater is being dumped into the water bodies which leads to the loss of water resources. However, treated wastewater should be viewed as a source of water that can be recycled and reused, which may reduce pressure for the natural freshwater (Smith et al., 2018). Water treatment and reuse can provide supplementary water resources in water stressed areas. Treated water can be reuse for irrigation, toilet flushing and other recreational purposes. Previous reports suggest that recycling of waste water was started successfully in Singapore and China (Lee & Tan, 2016; Meng, 2019). Several technologies are suitable for reclamation of treated wastewater includes adsorption technologies (Granular activated carbon, ion exchange), membrane technologies (ultra-filtration, reverse osmosis, nanofiltration, microfiltration) and physicochemical technologies include advanced oxidation processes (Wintgens et al., 2008).

2.6 Polyhydroxyalkanoate (PHA)

Recently, researchers are attracted towards recovery of polyhydroxyalkanoates from the municipal sludge. It leads to the reduction of cost of sludge management because of the production of high value biodegradable plastic polymers. These polymers are stored inside the variety bacteria as a storage material. Many microbes were identified as PHA producers includes *Paracoccus, Amaricoccus, Thauera, Azoarcus, Acidovorax, Zooglea* sp., *Rhodococcus, Flavisolibacter* , *Lampropedia hyalina* (Carvalho et al., 2014: Janarthanan et al., 2016: Puyol et al., 2017). For the production of biodegradable plastics, these polymers can be extracted from bacteria because of the similar properties of it to the petroleum-based plastics. This polymer can be used for applications in the packaging, agricultural, plastic and medical industries. The most common examples of PHAs are homopolymers of 3-polyhydroxybutyrate, copolymers with 3-hydroxyvalerate, 3-hydroxy-2-methylbutyrate, 3-hydroxyvalerate, and 3-hydroxy-2-methylvalerate (Pisco et al., 2009).

2.7 Single Cell Protein

Because of the rapid increase in the population, there are tremendous pressures on natural resources which may affect the environment. Several important resources such as organic substances and valuable nutrients can be found in wastewater. By recovering such valuable nutrients, pressure can be reduced on natural resources. Among the nutrients, protein is one of the major nutrients and can be recovered from wastewater which may can provide an alternative resource. Many technologies have been proposed for protein recovery includes adsorption, membrane separation and microbe-assisted protein recovery (Shahid et al., 2021).

The separation of the proteins from the wastewater could be an attractive low-cost alternative. For the recovery of proteins from the wastewater several ideas have been applied in which single-cell protein (SCP) is most important (Van Der Hoek et al., 2016: Meng et al., 2018). SCP production well known concept and referred to the edible microbes with high protein content. The wastewater contains a huge amount of a variety of substrates and protein which can be converted into the SCP by using microorganism. These microorganisms efficiently recovered nitrogen from wastewater which leads to reduction of environmental pollution. By this process, the organic contents from the wastewater will be recycled despite being lost into the environment (Hulsen et al., 2014).

2.8 Recovery of Metals

Metals are one of the contributors of water pollution. The main source of metals in water is man-made activities such as burning fossil fuels, mining, cement production, leather tanning, production of fertilizers, pesticides and plastics (Puyol et al., 2017). Recently, metals are also incorporated into the food, medicine and textiles through nanotechnology. These metals are deposited in sludge from liquid effluent. Many metals were identified in sludge, including Al, Cu, Fe, Mn, Ti, Mo, Zn, Ni, Sn, Cr, and Ag (Westerhoff et al., 2015). However, the metal composition can differ based on the human activities and geomorphology. Hence, there is an opportunity to recover these metals for reuse. It also reduces public and environmental risks connected with current sewage sludge disposal methods such as land disposal, landfill disposal, and incineration. Various biological methods are used for metals recovery includes bioleaching, immobilization etc. (Nancharaiah et al., 2016).

CONCLUSIONS

Resource recovery from municipal wastewater could be an environmentally sustainable approach to solve the problems related to waste treatment and management. Municipal wastewater can be viewed as a valuable resource for recovery of several products includes energy (biogas, and biohydrogen), nutrients (nitrogen and phosphorus), water, fertilizer, metals, biopolymer etc. There are many technologies which are widely acceptable to improve the efficacy of resource recovery from municipal wastewater which can reduce pollution and pressure on natural resources which ultimately responsible for circular economy and sustainability of the environment.

Statements and Declaration

Ethical statement: Not applicable

Competing interests: The author declares no conflicts of interest.

-Data availability: Not applicable

Acknowledgements: Not applicable

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Received: 23th Jule 2022; Accepted: 18th January 2023; First distribution: 18th September 2023