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An overview on Sludge to Energy

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ABSTRACT:-Instead of using energy to treat waste water; it is actually feasible for one to harness energy from wastes. Urban water systems and, in particular, wastewater treatment facilities are among the major energy consumers at municipal level worldwide. Estimates indicate that on an average these facilitiesalone may require about 1% to 3% of the total electric energy output of a country, representing a significant fraction of municipal energy bills. Specific power consumptionshould range between 20 and 45 kWh per population-equivalent served, per year, even though older plants may have even higher demands. This figure does not include wastewater conveyance (pumping) and residues post-processing. On the other hand, wastewater and its by-products contain energy in different forms: chemical, thermal and potential. Energy recovery from sewage sludge offers an opportunity for sustainable management of sewage sludge and energy. Anaerobic digestion and pyrolysis are among the most promising processes applicable for sewage sludge-to-energy conversion. This paper presents a brief overview of anaerobic digestion and pyrolysis in the application to bio-energy production from sewage sludge. Besides wastewater valorization by
exploitation of its chemical and thermal energy contents, closure of the wastewater cycle by recovery of the energy content of process residuals could allow significant additional energy recovery and increased greenhouse emissions abatement.

Keywords:- Water–energy; urban water cycle; wastewater treatment plant; waste sludge; energy demand; energy recovery; Sewage sludge; Energy recovery; Anaerobic digestion; Pyrolysis; Energy efficiency

I. INTRODUCTION:-

Sustainable energy management in the wastewater sector applies the concept of sustainable management to the energy involved in the treatment of wastewater. The energy used by the wastewater sector is usually the largest portion of the energy consumed by the urban water and wastewater utilities. The rising costs of electricity, the contribution to greenhouse gas emissions of the energy sector and the growing need to mitigate global warming, are driving wastewater utilities to rethink their energy management, adopting more energy efficient technologies and processes and investing in on-site renewable energy generation.

Among the water and wastewater services of a city, wastewater treatment is usually the most energy intense process.

Wastewater treatment plants are designed with the purpose of treating the influent sewage to a set quality before discharging it back into a water body, without real concern for the energy consumption of the treating units of a plant. These facilities play the important role to protect not only the water systems but also the human health, preventing the discharge of pathogens normally present in the municipal sewage. Despite the key role of wastewater facilities, energy consumption can not be ignored anymore because of its contribution to greenhouse gas emissions and the need to reduce the emissions to mitigate global warming, as established by the Kyoto Protocol in 1997 and most recently, by the Paris Agreement.Moreover, there is uncertainty concerning energy costs. Because for a wastewater utility energy costs represent the second highest cost after labour, an increase in energy rate would further increase the operational budget of a municipality, and consequently, the service rates for consumers.

Therefore, it is important for the wastewater sector to invest in strategies to limit the demand of energy from the grid in order to mitigate both costs and greenhouse gas emissions. According to current technology levels, specific

power consumption of state-of-the-art WWTPs should range between 20 and 45 kWh per PE (population equivalent) per year, even though some older plants may double these energy demands [8]. Other data indicate power consumption of between 0.3–2.1 kWh/m3 of treated wastewater in the EU, and between 0.41 to 0.87 kWh/m^3, in the U.S. ,depending on type of treatment, plant size and topography, etc.
On the other hand, wastewater contains energy in different forms: chemical, thermal and kinetic.

The chemical energy contained in wastewater has been estimated by different studies as ranging from approximately 10 to 14 kJ/g COD (1.67–2.33 kWh/m3 even assuming a diluted COD concentration of 600 mg/L), while thermal energy could yield about 21 MJ/m3 (5.8 kWh/m3) for a drop of 5^0C in wastewater temperature, and potential energy would yield just 30 kJ/m3 (0.008 kWh/m3) over a 10 m drop. The first two numbers clearly illustrate the energy-saving potential of innovative wastewater management, highlighting the fact that the energy stored in wastewater is about six to nine times higher than the electric energy needed for treatment. Assuming this energy could be practically exploited, WWTPs could be transformed into energy-neutral or even in net energy producers. Energy demand (mostly electric) of wastewater treatment to required standards is a significant component of the urban water cycle overall costs. It was estimated that 30% to 35% of total cost of wastewater treatment facilities in the U.S.A. is due to electric energy. More stringent limits for nutrient removal or mandatory removal of presently unregulated contaminants, such as contaminants of emerging concern (CEC) and pharmaceuticals and personal care products (PPCP), with introduction of additional process steps, might imply a significant increase in energy demand
of treatment facilities, therefore energy reduction and recovery represent an important sustainability issue for maintaining required standards.

II. LITERATURE REVIEW

In his studies the author Adam Smolin ski, JanuszKarwot, Jan Bondaruk and Andrzej Ba (2019) aims to analyse the economic feasibility of generating a novel, innovative bio-fuel—bio-energyobtained from deposit bio-components by means of a pilot installation of sewage sludgebio-conversion.In the present study, 23 bioconversion cycles were conducted taking intoconsideration the different contents, types of high carbohydrate additives, moisture content of themixture as well as the shape of the bed elements. Sewage sludge stabilized by means of anaerobic digestion carried out in closed fermentation chambers is the final product.

The author IstavanZsirai in his paper “Sewage to Slude as Renewable Energy” (2016) Sewage sludge is an inevitable and unavoidable by-product of sewage treatment. The amount produced is massive and is also expected to rise rapidly in Europe in particular, as a result of the higher treatment standards provided through the EU Commissions, gap closing actions in CEE past and future 20 years. Expected to reach 13,5M Tds/a volume by 2020.Sewage sludge is a renewable, negative-cost organic material that is well suited for the energy production via different processes, methods.

In this work by D. Panepinto& G. Genon (2014) he as examined, both from a technological and anenvironmental point of view, the thermal solutions (firstly the direct combustion in incineration plant, but also gasification) for the sludge deriving from the main Italian wastewater plant (plant of the metropolitan area of Torino).

In this article by Mika Horttanainen, JuhaKaikko, Riikka Bergman, MinnaPasila-Lehtinen, JanneNerg in 2011, optional design alternatives of a Waste-to-Combined Heat and Power (WtCHP) concept are studied. The concept was first introduced by Einco and has been studied theoretically by Horttanainen et al. Different design options are introduced for different cases of energy need. The performance and economy of the options are analyzed and compared with Waste-to-Heat (WtH) plants where the sludge is used to generate heat only. Furthermore, the WtCHP concept is compared to the competing sludge treatment technologies by analyzing the strengths and weaknesses of the main alternatives. Using this kind of analysis, the applications or regions where the WtCHP concept is a competitive choice are determined.

Although numerous technologies for the recovery of water, energy, fertilizer and other products from wastewater have been explored in the academic arena, few of these have ever been applied on large scale due to technical immaturity and/or non-technical bottlenecks. In all, we have identified nine such bottlenecks mentioned in scientific literature that may hinder the successful integration of RRRs into wastewater treatment plants (WWTPs).

To achieve the transition from WWTPs to WRFs, resource recovery needs to be considered a strategic goal from the earliest process design and planning stages of new processes. Designing and implementing a WRF requires decisions in fields that are far beyond the traditional responsibilities of WMUs are depicted in the paper byPhilipp Kehrein , Mark van Loosdrecht, Patricia Osseweijer , Marianna Garfí , Jo Dewulf and John Posada (2020).

In this research by Timothy E. Seiple, Andre M. Coleman, Richard L. Skaggs (2017), the first method computes CHP sludge input requirements as a function of the specific energy of sludge, which ranges from 8.5 to17.0 MJ/kg. Digester gas was assumed to supply 100% of the fuel for each system.

The second method computes CHP sludge requirements based on the reported relationship between influent flow and potential electric capacity in a CHP system. A CHP system can generate approximately 26 kW of electric capacity per 3.8 Ml (1 Mg al) of influent flow (EPA, 2011).methodologies wastewater, generating millions of tons of sludge annually, which must be treated for disposal or beneficial reuse.

Sewage sludge is a byproduct of wastewater treatment plants (WWTP), considered valuable forest contain of nutrient and energy but also a potential treat to humans and environment because on the presence of organic pollutant and heavy metals. Sustainable solution and best available techniques for the treatment and disposal of sewage sludge, including recovery of energy and nutrients, are currently being discussed in a European Union as concluded by DinkoĐurđevi´, Paolo Blecich and ŽeljkoJuri´ (2019) in his studies

Anaerobic digestion of sewage sludge from methane rich biogas, which can be utilized as fuel to offset heat and electricity consumption at the waste water treatment sector.Sludge Pyrolysis is an in innovative Process that can convert both raw and digested large into useful bio energy in the forms of oil and gas, farming bio-char as a byproduct that is environmentally resistant and hold potential for carbon sequestration and soil conditioning is studied in YuchengCaoab, ArturPawłowski (2018).

This study presented by**JumokeOladejo, Kaiqi Shi, Xiang Luo ,Gang Yang and Tao Wu**(2018), a simple review of three sewage to energy recovery routes: -

- Anaerobic digestion
- Combustion
- Pyrolysis and gasification.

This study focuses on the review of various commercially viable sludge conversion processes and technologies used for energy recovery from sewage sludge.

In combustion, it involves the high temperature oxidation of fuels to obtain heat, carbon dioxide, water vapour and other trace gasesuse of combustion technology for waste materials such as sludge can be used for primarily generating heat (conventional combustion) or for reducing the volume of the waste materials (incineration).

In pyrolysis, it is used for producing bio-oil, solid char and gaseous fuel and referred to as incomplete gasification and gasification thermo-chemical conversion of sewage sludge’s organic content into high value gases such as H2 and CO known as synthesis gas, as well as CO2, CH4, H2O and other hydrocarbons is the main basis for gasification.

In this paper by M.H. Romdhana, Anwar Hamasaiid, Bruno Ladevie, Didier Lecomte (2019) energy valorization of sewage sludge using a batch fry–drying process. Drying processes was carried out by emerging the cylindrical samples of the sewage sludge in the preheated recycled cooking oil.In this paper used the fry-drying process Frying, one of the oldest processes of the food industry consists of drying by contact with hot oil and involves simultaneous heat and mass transfer. The sewage sludge used in the experiments was produced by TEMBEC SA Company (Saint-Gaudens, France), manufacturing of pulp paper.It was found that the models were able to predict moisture content and oil uptake in close agreement with experimentally determined data.

In this work by Sintering chracteristics be of sewage sludge ashes at elevated temperatureLing wang ,Geirskjevrak , Johan E.Hustab ,Morten G.Gronli (2012),sintering characteristics and minerals transformation beware up sludge Ash (SSA) at elevated temperature where investigate by using Ash fusion analyser, x-ray fluorescence (XRF),X-RAY diffraction (XRD) and scanning electron microscopic equipped with energy dispersive x-ray spectrometry (SEM/EDX).All samples were at desired final temperatures for 1 hour to ensure sufficient time for chemical interaction and mineral phase transformation.

At present most of the stage of water treatment plant (WWTP) in the Czech Republican elsewhere is applied directly or indirectly to the agriculture land are disposed by island filling.This paper presentsthe current situation of Sludge disposal in the Czech republic and some other European countries. Environmental legislation valid for the European Union is taken into account.Thermal treatment of sludge in cement work is analysed in detail as a promising approach. The reason for this selection consists in the possibility of utilising waste heat for drying wet sludge as depicted in there research by Pavelstasta,JoroslavBebar ,LadisdlavBebar, Petrstehlik, Joroslav Oral (2005)

Sustainability of domestic sewage sludge disposal by Claudia BrunaRizzardini, Daniele Goi (2014), Activated sludge is now one of the most widely used biological process for the treatment of water waste from medium to large populations. It produces high amount of Sewage Sludge that can manage the received in two main ways.Applying the criteria up elevation of the last official document European Union about Sewage sludge land application, the working Document on sludge (3rd draft, 2000)". The report brought out good sewage sludge from small wastewater treatment plant and soil quality suggesting a suitable application.Hydraulic and control and overloading caused of soil pores, soil water logging, odours and contamination of food crop.

U.S municipal waste water contains approximately 160 trillion Btu/y of influent chemical energy, but very little is recovered and utilised Nationwide.Hydro-chemical liquification (HTL)is a thermo-chemical process that convert bio-mass into a bio kit intermediate that can be upgrade to a variety liquid fuels.

HTL provides an approximatemethod to enhance energy recovery and wastewater treatment plants but transfer the underutilized municipal wastewater solids into a renewable, cost-effective feed stocks transportation bio fuels.

In this study, they estimate total national economic sludge feedstock supply by performing discounted cash flow analyses at >15000 U.S. as conclude in the paper titled Municipal wastewater sludge as a renewable, Cost-effective feedstock for transportation bio-fuels using hydrothermal liquefaction by Timothy E.Seiple, Richard L.Skaggs, Lauren Fillmore, Andre M.Coleman (2020).

Pyrolysis can convert wastewater solids into useful by-product such as Pyrolysis gas (py-gas),bio-oil and bio-char. However, Pyrolysis also yield organic rich Aqueous Pyrolysis Liquid (APL), which presently has no beneficial use. Autocatalytic Pyrolysis can beneficially increases py-gas production and eliminate bio oil, however,APL is still generated.This study aimed to utilise APL was Co-digestion.

Autocatalytic Pyrolysis is a recently developed process that uses previously produced bio-char from bio-solids Pyrolysis increases py-gas while decreasing bio-oil and APL production as told in their studies by Saba SeyediKaushik, Venkiteshwaran, Nicholas Benn and Daniel Zitomer (2020)

The author N Vatachi in his studies told that Wastewater treatment in these processes results in increasing volumes of sewage sludge. The elimination of this sludge is a permanent concern at global level because of the dangers to the environment, consisting of the high content of organic pollutants, toxic and heavy metals proposes a review of current conversion methods and technologies for energy recovery from sewage sludge.

Anaerobic digestion is a widely used method of biological conversion because of its low cost and the ability to use high-humidity organic waste without reducing high calorific value of the produced biogas (methane and carbon dioxide).

Instead of using energy to treat waste water; it is actually feasible for one to harness energy from wastes as well as treating it using a Microbial Fuel Cell (MFC) as studied by Banadda N and Kiyingi D 2014). An MFC generates electricity from sewage with the help of bacteria. The generation of electricity from sewage as well as sewage treatment in the same period need to develop and improve on existing waste water treatment technologies that are environmentally sustainable in these times of energy scarcity.

In his research by IstvanZsirai (2016) he depicted that Developed countries ensure that the public health and the environment are protected when sewage sludge is disposed of by each of the following accepted methods

- Application to the land as soil conditioner or fertilizer, agriculture usage
- Disposal to ocean (in the sea), (not permitted in the EU)
- Disposal on land by placing it in a surface disposal site (not permitted in the EU, to be phased out)
- Placing it in a municipal solid waste landfill unit (no longer permitted in the EU)
- "Bio-soils" production for sale in market place, composting, land reclamation, etc
- Incineration (disposal to a certain extend in the air as consequence of incineration)
- Sludge to energy

The possibility of wastewater treatment and electricity production using a microbial fuel cell with Cu–B alloy as the cathode catalyst technical device that can combine electricity production with wastewater treatment is a microbial fuel cell (MFC). MFCs are ecological sources of electric energy which produce electricity from wastewater by Paweł P. Włodarczyk and Barbara Włodarczyk (2019)

Wastewater reuse in agriculture involves the further use of "treated" wastewater for crop irrigation. The use of treated wastewater in agriculture benefits human health, the environment and the economy. One of the most recognized benefits of wastewater use in agriculture is the associated decrease in pressure on freshwater sources.The search for alternative irrigation sources is believed to be vital to ensure food safety and to preserve natural water bodies as concluded by María Fernanda Jaramillo and Inés Restrepo in his studies (2017).

In his paper by G Venkatesh (2018) a South African case study , the authors, in a detail analyse energy recovery possibilities from wastewater through biomass production, combustion and gasification of bio-solids, generation of biogas, production of bio-ethanol, heat recovery and using microbial fuel.Cells running on bio-hydrogen to generate electricity, established the potential at 3.2 to 9 GWTH of energy which is equivalent to about 7% of the country's electricity generation.

In this project the researchers Dr. Robert Daschner (2020) wanted to produce advanced bio-fuels from waste, which in this particular case will be sewage sludge. Theyhad set up the plant,operated and demonstrated the technology in operation.

The plant produced over 20,000,01 of bio-crude oil, Sewage sludge refers to the final solid component produce during wastewater treatment.This project marks the first pre-commercial scale development of the technology processing up to 2100 tons per year of dried sewage sludge into 2,10,000 liters per year of liquid bio-fuels and up to 30,000 kg of green hydrogen.

According to the authorAnthony Quansah (2018), as reported by WRC, there are currently no definite solution as which treatment method is most suitable as the physio-chemical properties of sludge is highly variable and most solution have not been demonstrated at scale.The entire city population operates on three kinds of wastewater collection which include pit-latrine sept-age and sewage network system.

Wastewater treatment processes produce sewage sludge, which has to be discharged after an appropriate treatment. Nowadays, there are several new technologies in use or in development. The main aims of these methods are recovery and reuse of either the nutrients or the energy at acceptable costs. Besides the production of biogas in anaerobic digestion, the calorific value of sludge can also be recovered in the form of heat.The costs for sewage sludge treatment often represent more than 50% of total wastewater treatment cost as concluded by Rulkens (2007).

Wastewater has been recognized as a resource rather than a waste stream for over a decade now. It contains resources that can be recovered with a variety of technologies into reusable water, energy, fertilizers and other valuable products. Recovering resources that can be produced in quantities and at a cost that match the current market demand and prices and tackle projected future resource.The aerobic granular sludge process, also known as the NEREDA technology was successfully introduced globally at several full-scale wastewater treatment plants in recent years and is considered more resource efficient than the conventional activated sludge process as conducted by Philipp Kehrein, Patricia Osseweijer and John Posada (2020)

The objective of this literature review by Cunningham, Michael (2016) is to assess if slow pyrolysis will cost effectively and safely treat faecal sludge in low-income countries at the municipal treatment plant scale. This task is completed by:

• Identifying parameters that predict if faecal sludge char provides each of the five potential benefits based on the results of other feedstocks
• Determining the influence of operating conditions on achieving each of the five potential benefits
• Estimating if faecal sludge char heavy metal concentrations exceed proposed standards and existing regulations for land application
• Discussing the integration of pyrolysis with existing faecal sludge treatment plants
• Evaluating existing slow pyrolysis units
• Reviewing char applications beyond the five potential benefits
• Identify future research needs

A new approach considers sludge to be a fuel which can be used on-site to produce electricity as suggested by Nicholas P. G. Lumley (2013). Electrical power generation fueled by sludge may serve to reduce the volume of hazardous waste requiring land disposal and create economic value for WWTP operators.

A technical analysis follows which determines that such a system can be built using currently available technologies. Finally, an economic analysis concludes that a gasification based power system can be economically viable for WWTPs with raw sewage flows of 0.115 m3/s, or about 2.2 million gallons per day.

The development of technologies for the production and the exploitation of renewable energy sources is currently pushed by legislation and/or public investments worldwide, especially in those regions where the highest energy consumption is located.

Biogas can be obtained as a byproduct in the anaerobic digestion of the sludge produced in the wastewater treatment: the main goal of the anaerobic digestion is not the biogas production but the pathogen reduction and stabilization aiming at obtaining manageable bio-solids its uses vary from electricity and heat generation (principally) - which is the main use in Europe and Italy as well - to the injection in the natural gas grids and the utilization as vehicle fuel after proper treatment as concluded by the Simone Gamba, Laura A. Pellegrini, Stefano Langè in 2014.

Treatment of municipal wastewater results worldwide in the production of large amounts of sewage sludge. The major part of the dry matter content of this sludge consists of nontoxic organic compounds, in general a combination of primary sludge and secondary (microbiological) sludge.Besides the increasing focus on the recovery and reuse of energy, in-organics, and phosphorous, there is also an increasing focus to solve completely the problem of the toxic organics and inorganic compounds in sludge. In the assessment and selection of options for energy recovery by means of biological methods, this aspect has to be taken into account as depicted by WimRulkens (2007).

The author Orlando, Florida, United States, 2011 studied that the Digested sludge is a complex mixture of primary mineral grains and fragments of biological and industrial materials. Sewage sludge refers to the residual, semi-solid material left from the treatment of wastewater. The management of sludge plays an important role in wastewater treatment works. Sludge management can be divided into sludge production, treatment, and disposal.

In recent years, methods formerly used for the disposal of sewage sludge, including landfill, incineration, ocean dumping and disposal on agricultural land have become much less acceptable.

III. CONCLUSION

Energy recovery from sewage sludge represents an important strategic lever for sustainable management of sewage sludge and energy. Anaerobic digestion and pyrolysis are among the most promising and sustainable processes applicable for sewage sludge to bio-energy conversion. Anaerobic digestion of sewage sludge, which has been well developed, can produces bio-energy in the form of biogas, which is a robust fuel that is suitable for heat and electricitygeneration. However, the anaerobic digestion process has the ineradicable limitation that it is not able to sufficiently recoverenergy from sewage sludge. The digested sludge still has considerablepotential for bio-energy production on the one hand, on theother hand places a wide range of impacts on the environment andon public health if untreated or un-appropriately treated.

Sludge pyrolysis is an environmental-friendly innovative process that can successfully convert different types of sludgeincluding primary, waste activated and digested sludge into usefulbio-energy in the form of oil and gas, forming bio-char as a by-productthat is environmentally resistant and can be used for carbonsequestration and soil conditioning. Practical deployment of sludgepyrolysis is expectable in the near future.

An interesting observation is the lack of data to accurately back the high efficiency of mostpyrolysis and gasification systems as they fail to account for the energy intensive pre-processing stagewhich offsets a considerable fraction of the recovered energy and could lead to negative energy balance.

As a result, innovative pathways and research using these technologies commercially are requiredsuch as coupling of biochemical and thermo-chemical systems to optimise energy recovery. This couldbe easily conceptualised as an integrated bio-refinery approach which can be designed appropriatelyfor the maximization of energy outputs to reduce adverse environmental impacts. All considered technologies in this work show the need of further research and development into co-utilization of sludge, operating condition optimization and effective technology scale-up for maximizing energy recovered while reducing cost and emissions.

The optimal solution for sewage sludge management depends on the expected quantities and sludge properties, the capital investment, the operational challenges and costs, the ecological and technological constraints, the legal and location restrictions, as well as on the chosen type of application

or disposal of by-products. The fastest growing methods for sewage sludge treatment and disposal are anaerobic digestion and incineration. Incineration of sewage sludge has become more interesting lately because it significantly reduces the sludge volume and mass, destroys the harmful substances, and can be coupled to energy recovery systems.

Energy recovery from wastewater process residuals may significantly contribute to improving the energy balance of WWTPs. In addition to traditional systems such as incineration, technologies such as pyrolysis and hydrothermal carbonization allow recovery of liquid and solid phases with energy values that may be transported more easily than biogas for site use. These may also find applications in the chemical synthesis industry for extraction of other valuable components and originate Circular Economy cycles at the local level.

Urban water systems need the supply of relevant amounts of energy for their operation. Future, more stringent emissions regulations on nutrients or emerging compounds may further increase these requirements. Improving internal energy efficiency by process modification and technological upgradeand exploiting available incoming energy wisely could lead in the next future to the “zero energy” wastewater treatment plant concept implementation, which not only reduces facilities’ energy footprint but allows recovery of wastewater-embedded resources for reuse. All these processes would require in-depth feasibility, technical, economic and life cycle assessment for determining their suitability in the low carbon future.

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