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Wastewater sludge characteristics, treatment techniques and energy production

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A R T I C L E I N F O

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The research presents an overview on sludge types, characteristics, and methods of treatment. Additionally, using the sludge as an energy source for future plans was studied as well. The paper focused mainly on analyzing different sludge characteristics based on the previous studies. Wastewater sludge produced from the primary, secondary, and tertiary treatment processes was analyzed. It was mainly composed of many organic and inorganic materials. Some of the materials were removed by physical and other required chemical or biological processes. Most of the sludge was solid, semi-solid, and muddy with the harmful substances such as proteins, phenols, and hazardous materials. The study explained different methods of energy production as well. At the end, it was concluded that every type of sludge could provide energy and be a basic financial product for the selected area, and keep environment safely and healthy as well. The calculated quantity of dry sludge for 1,000,000 inhabitants in Erbil City, Kurdistan Region-Iraq, was 50,000 kg/d, which produced calorific value of $9.5 \cdot 10^7$ K. cal./day. Furthermore, the essential area for under drain sand bed area was 5,100 m^2.

1. Introduction

Nowadays, due to various human activities and rapid increasing of the population growth, the waste production is highly increased, especially for those cities which face these problems, and require proper managing of this disposed wastes, as well as, switching to alternative energy sources for developing Erbil economy infrastructure. Erbil City is the Capital of Kurdistan Region, Iraq. However, most undeveloped countries deal with the waste production without getting benefit from it. Meanwhile, the use of proper techniques will not cause such big problems, although, it will have an effect on the surrounding environment. For these reasons, this important topic has been selected in order to evaluate the produced sludge form Erbil City's wastewater, and to familiarize future researchers with this problem and motivate them to try and find appropriate methods for sludge management and to help with the lack of energy sources form the obtained sludge amount. It is obvious that sludge types depend on the sources of sludge production, for instance, the sewage sludge has characteristics different from sludge produced from municipal wastewater. It should be considered that the high amount of sludge disposal causes difficulty, therefore the optimization of the existing system and final decision is very crucial for the study area. Though, due to various sludge characteristics and large amount of water

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content, it can be used as a potential energy source for future if it is properly used (Kurniawan et al., 2018). It is also observed that anaerobic digestion is preferable, for variety of sludge wastewater, but this method is limited in general (Vatachi, 2019).

The current study reviewed numerous previous papers, in order to find a suitable solution for the selected waste problems in the study area. Unfortunately, this subject has not been studied up to now. Therefore, the problems were analyzed and the appropriate methods of treatment were determined for each case based on the previous experiences in this subject. Karagiannidis et al. (2011) worked on sewage sludge production and utilization in Greece. Furthermore, Johnson et al. (2014) published a paper on waste sludge in industry. Kollmann et al. (2017) worked on energy production from wastewater practical aspects of integrating a wastewater treatment plant. Moreover, Demirbas et al. (2017) published their works on the sludge. Guo et al. (2019) published a research on green energy produced from wastewater treatment plant (WWTP). De Azevedo et al. (2019) carried a research on sludge industry and safe disposal method for the environment. Salama et al. (2020) worked on activated sludge for sewage treatment plant in Morocco. On the other hand, all the studies suggested several methods of energy production from different sludge types and sources in different countries as well. Dempsey and Jeon (2001) studied sludge characteristics produced from mine drainage. Also, Janczukowicz et al. (2001) worked on activated sludge from a sequencing batch reactor. Degaard Paulsrud and Karlsson (2002) conducted a research on wastewater sludge. Later, Mesdaghinia et al. (2004) studied characteristics of sludge produced from wastewater treatment plant. Sievers et al. (2004) published a research on sludge treatment. Geng et al. (2007) carried out the investigation on sludge characteristics. Asia et al. (2006) published research on sludge characterization for petroleum industry. Aziz et al. (2012) reported that powdered activated carbon improved sludge characteristics, especially Sludge Volume Index (SVI). Next, Nei et al. (2014) determined the compost form sludge of the sewage of pharmaceuticals. Mills et al. (2014) studied evaluation of the future sewage sludge for energy technologies. Ayoub, et al. (2016) worked on energy production from wastewater sludge. Qian, et al. (2016) carried out the investigation on municipal sewage sludge treatment. Amudha et al. (2016) conducted a research on sludge efficiency. Additionally Kim et al. (2017) published a research on sewage sludge treatment.

The review article took those studies as a fundamental, especially those that discussed the most common technologies that can be used for the production of sludge from wastewater. The study also performed an assessment of the impact of obtained sludge on the environment. Furthermore, it was focused on other challenges to convert waste for energy sources like power, heat, and gas as well. In addition, the study evaluated economic and environmental safety aspects by considering sustainability of the environment (Oladejo et al., 2018).

Erbil City faces the deficit in power and energy production. It is clear that there is a gap between the available sources and demand, and for this reason, it is important to implement new sources of energy production and cost as well. In addition, the production of sludge in the selected city is highly increased, due to rapid growth of the population, urbanization, developing several projects, and industrial activity. The use of sludge from those sources should be managed in order to decrease the disposing impact on nature.

To date, a number of researches published articles on wastewater quality, treatment, and reusing in Erbil City, Kurdistan Region-Iraq (Aziz, 2004; Amin and Aziz, 2005; Bapeer 2010; Shekha et al., 2010; Aziz and Ali, 2018; Aziz, 2020; Aziz et al., 2020). But so far, there is no published work on sludge characteristics, treatment, products, and energy production in the Erbil City and in Kurdistan Region-Iraq. Consequently, the objective of this research was to study the sludge quality, treatment methods, and outcomes of the sludge processing. Additionally, the current work was focused on the sludge quantity and obtained energy from sludge processing in Erbil City.

2. Produced sludge in the WWTP

The study focused on the review of the previous studies, presentation of the way of disposing sludge and converting it to potential energy, and minimization of the sludge volume in the environment. Usually, sludge is produced from sewage or wastewater treatment processes (Figure 1). It is mainly classified into two types called sludge and activated sludge that can be provided in the activated sludge treatment processes.

Normally, WWTP includes primary, secondary, and advanced treatment processes. Sludge is produced throughout several wastewater treatment processes, Figure 1. Sludge comprises of liquid and solids. Most part of the sludge is liquid part. Sludge is categorized into the following groups:

- Primary sludge: contains settleable solids carried in the raw wastewater;
- Secondary sludge: consists of biological solids, as well as extra settleable solids.
- Sludge produced in advanced treatment process: may contain viruses, heavy metals, phosphorous, or nitrogen.

The objectives of the sludge treatment are:

- To decrease moisture content in the sludge (Volume reduction);

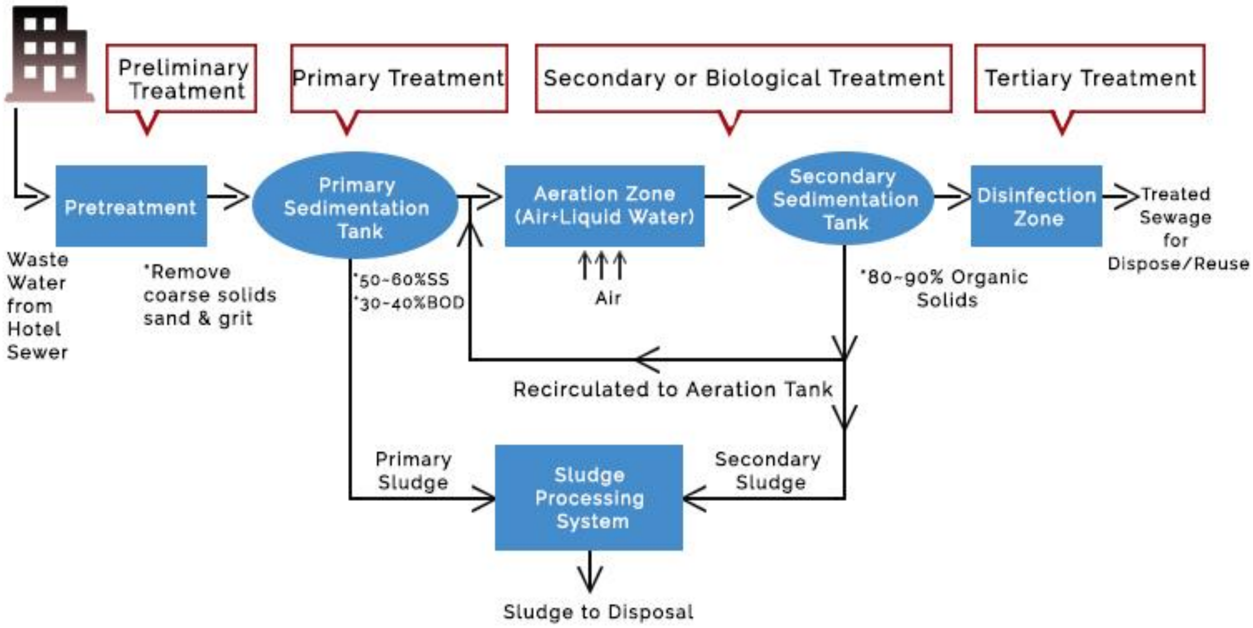

Figure 1. Produced sludge at typical WWTP (http://neoakruthi.com/blog/sewage-treatment-plant-for-hotels.html)

- To remove organic matters;
- To destroy microorganisms; and
- To eliminate toxic materials.

3. Sludge characteristics

Wastewater sludge type is solid, semi-solid, or muddy liquid where each of those consists of the various organic or non-organic materials, heavy metals, pesticides, polycyclicaromatic, phenols, and many other materials. The main characteristics of sludge are explained in (Metcalf and Eddy, 2014) as follows:

- Screening: It contains both organic and inorganic matter;
- Grit: It involves organic and inorganic matter, especially fats and grease;
- Scum/Grease: It consists of the floatable materials, oil and grease, animal fats, food wastes, vegetable and fruit skins, paper and cotton, cigarette tips, and plastic materials;
- Primary sludge: It is mostly gray and slimy;
- Sludge from chemical: It contains much iron;
- Trickling-filter sludge: It is produced from trickling filters flocculent, and relatively inoffensive when fresh;
- Aerobically digested bio solids: It has a flocculent appearance;
- An aerobically digested bio solids: Those contain large quantity of gas or hot tar, burnt rubber that produce methane gas; and
- Compost: Such as recycled compost, wood chips which can be used for composting.

Most of the conventional municipal wastewater sludge is mainly composed of sludge from primary sedimentation tanks (composed of organic and inorganic materials coming from the raw wastewater) and sludge from the secondary sedimentation tanks following biological treatment (influenced by the wastewater source and primary sedimentation tank operation). This sludge is also called activated sludge which involves the excess microorganism cells from the biological treatment process.

Each type of wastewater requires definite treatment process and generally it depends on the source and characteristics of the unprocessed wastewater. Accordingly, produced sludge from different treatment processes has various degrees of sludge quality. Table 1 illustrates typical characteristics of primary and secondary sludge. Details of sludge characteristics are shown in Table 2.

Yan et al. (2009) reported that numerous heavy metals were available in the wastewater sludge. Essentially, phosphor and potassium have both a high fertilizer value, while silica suggests good properties for soil stabilization applications (CORE, 2022).

These characteristics offer good chance for the recovery of fertilizers and construction materials from sewage sludge (CORE, 2022). It can be observed that wastewater sort and treatment technology have the effect on the sludge characteristics.

Table 1
Typical properties of primary and secondary sludge (Metcalf and Eddy, 2014)

Parameter	Primary sludge	Secondary activated sludge
pH	55 - 8.0	6.6 - 8.0
Alkalinity (mg/L as $CaCO_3$)	600 - 1,500	550 - 1,200
Total solids % (TS)	4 - 9	0.6 - 1.2
Volatile solids (% of TS)	65 - 80	60 - 85
Protein (% of TS)	18 - 30	30 - 40
Fats and grease (% of TS)		
Ether soluble	5 - 30	-
Cellulose (% of TS)	8 - 16	-
Nitrogen (N. % of TS)	1.4 - 4.2	2.5 - 5.0
Phosphorus (P_2O_5 % of TS)	0.6 - 2.9	3 - 10
Organic acids (mg/L as HAc)	250 - 1,800	1,000 -
Energy content, kJ/kg TS	24,000 - 28,000	18,000 - 23,000

Table 2
Summary of previous studies for sludge types and techniques

No.	References	Sludge sources	Techniques	Parameters
1	Janczukowicz et al. (2001)	Activated Sludge	Continuous flow	SVI: 20 - 600 ml/g
			Discontinuous flow	100 - 500 ml/g
			Continuous flow with mixing tank before the reactor	70
			Sequencing batch reactor (SBR)	40 - 60
			Experimental SBR	30 - 50
2	Uygur and Kargi (2004)	Landfill leachate	SBR	pH 8.6 COD mg /L NH_4N mg /L $NO_3.N$ mg /L $PO_4.P$ mg /L TSS mg /L TS mg /L Salinity % Dissolved oxygen mg /L
3	Kupka et al. (2008)	Municipal		13.8 (LCV)
4	Fonts et al. (2009)	Municipal		12.3 (HHV)
5	Aziz et al. (2012)	Landfill leachate	Powdered activated carbon (PAC)	SVI<100 mL/g
6	Manara and Zabaniotou (2012)	Primary treatment		4,200 (kWh/t)
		Biological treatment		4,100 (kWh/t)
		(Low) Biological treatment		4,800 (kWh/t)
		(Low and Mid)		
		Primary and Biological		4,600 (kWh/t)
		(Mix) Digested		3,000

Table 2 Continued
Summary of previous studies for sludge types and techniques

No.	References	Sludge sources	Techniques	Parameters
7	Folgueras et al. (2013)	Municipal		17.75
8	Li et al. (2014)	Municipal		15.59 (HHV)
9	Magdziarz and Werle (2014)	Thermal power plant		13.12 (HHV)
10	Chiou and Wu (2014)	Pulp industries Textile Industries		8.73 5.1
11	Atienza-Martinez et al. (2015)	Digested (municipal)		12.79 (HHV)
12	Ayoub et al. (2016)	Sewage	Chemical Precipitation	Biogas 440 m^3/d Methane 286 m^3/d Electric power 400 KWh/d
13	Vatachi (2019)	Wastewater	Anaerobic digestion Combustion Pirolysis Gasification	Biogas Flue gas Bio char Bio oil Synthesis gas Tar Heat - Ash

4. Methods of sludge treatment

Generally, there are various treatment processes available to deal with the sludge, which are mainly based on the sludge composition types. For instance, for sewage sludge the methods of lime stabilization, dewatering, thickening, drying, composting, and the aerobic methods are applicable. Although, sludge that consists of nutrients can be used for fertilizer purposes. However, there is not any treatment process required for purifying the sludge that is produced from sewage. Meanwhile, toxic materials produced as a result of industrial and commercial treatment processes that are thrown into the sewage system can be used for farmlands. Moreover, some of the sludge types require to be disposed on landfilleds or incinerated depending on its composition.

However, the available sludge from WWTP has the vital role in environmental engineering, because it requires a treatment before disposing (Demirbas et al., 2017).

Sludge should be treated for the following purposes: reduction of moisture content (Volume reduction), removal of organic matter, destruction of microorganisms, and removal of toxic material.

The important techniques that should be taken into account are thickening, digestion, conditioning, dewatering, heat drying, and incineration. After the following techniques the final treated sludge can be disposed into the environment.

4.1. Thickening

Thickening reduces moisture content of sludge. Types of thickening process are: gravity thickening, air flotation, and centrifugation.

4.2. Digestion

There is aerobic and anaerobic decomposition of sludge. Later, the digested sludge can be sent to mechanical filters or sand beds (Vatachi, 2019), Figure 2. Table 3 illustrates typical chemical composition and properties of untreated/digested sludge.

4.3. Conditioning

Conditioning enhances the drainability of digested sludge. Methods adopted are elutriation (involves passage of air to separate particles), chemical conditioning (addition of coagulants), freezing etc.

4.4. Dewatering

The aim of dewatering is to reduce volume of sludge and increase concentration of bio solids, Figure 9. Dewatering can be achieved on sand drying beds or bed filters, Figure 3 (EEA, 1998).

4.5. Heat drying

Heat drying process is carried out in kiln at 350 °C. It decreases water content. Dried sludge is used as soil conditioner.

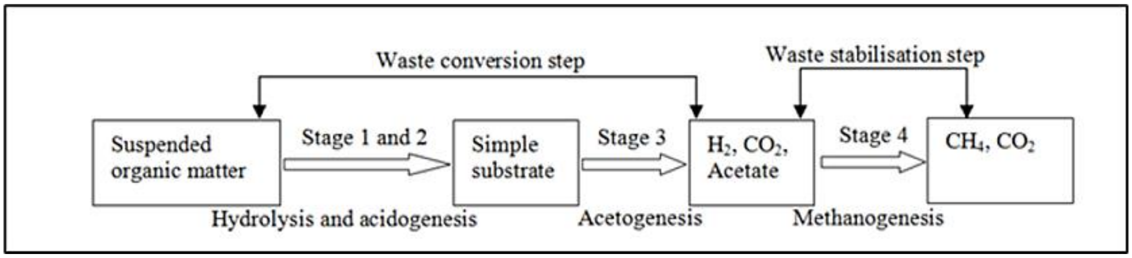

Figure 2. Stages of anaerobic digestion (Vatachi, 2019)

Table 3
Typical chemical composition and properties of untreated/digested sludge (Yan et al., 2009)

Item/Sludge	Untreated Primary	Digested Primary
Total dry solids (TS), %	2.0 - 8.0	6.0 - 12.0
Volatile solids (% of TS)	60 - 80	30 - 60
Grease and fats (% of TS)		
Ether soluble	6 - 30	5 - 20
Ether extract	7 - 35	-
Protein (% of TS)	20 - 30	15 - 20
Nitrogen (N,% of TS)	13 - 4	16 - 6.0
Phosphorous (P_2O_5, % of TS)	0.8 - 2.8	1.5 - 4.0
Potash (K_2O, % of TS)	0 - 1	0 - 30
Cellulose (% of 'TS)	8.0 - 15.0	8.0 - 15.0
Iron (not as sulfide)	2.0 - 4.0	3.0 - 8.0
Silica (SiO_2, % of TS)	15.0 - 20.0	10.0 - 20.0
Alkalinity (mg/L as $CaCO_3$)	500 - 1,500	2,500 - 3,500
Organic acids (mg/L as HAc)	200 - 2,000	100 - 600
Energy content	10,000 - 12,500	4,000 - 6,000
pH	5.0 - 8.0	6.5 - 7.5
Polymer		
Protein (sludge)	217 - 353	
Proton (EPS)	28 - 56	
Humic substances (Sludge)	73 - 195	
Humic substances (EPS)	17 - 51	
Carbohydrate (Sludge)	55 - 93	
Carbohydrate (EPS)	5.7 - 40	
Total extracted (EPS)	52 - I 19	

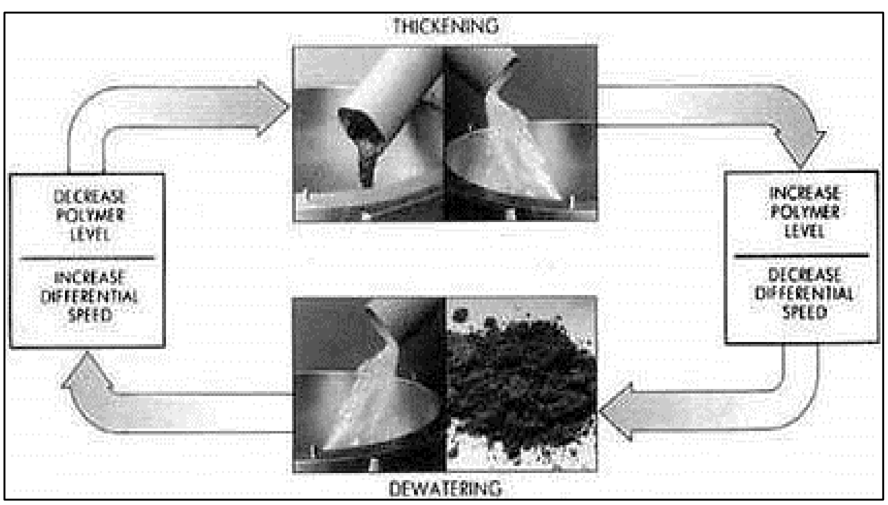

Figure 3. Sludge dewatering (EEA, 1998)

4.6. Incineration

Incineration is performed at temperature from 650 °C to 750 °C to burn the organic matter and other materials, Figure 4. It represents the combustion of sludge. Residual ash after incineration process is send to solid waste landfill site.

Each sludge treatment method has its benefits and shortcomings. Selection of a suitable sludge treatment system depends on land availability, energy, cost of construction and operation/maintenance, objective of the treatment etc.

Details of sludge treatment processes are shown in Table 4. Finally, Kumar et al. (2017) presented the most appropriate methods for sludge treatment in Figure 5.

Additionally, Figure 6 illustrates details of the typical sludge quantities in wastewater treatment plant.

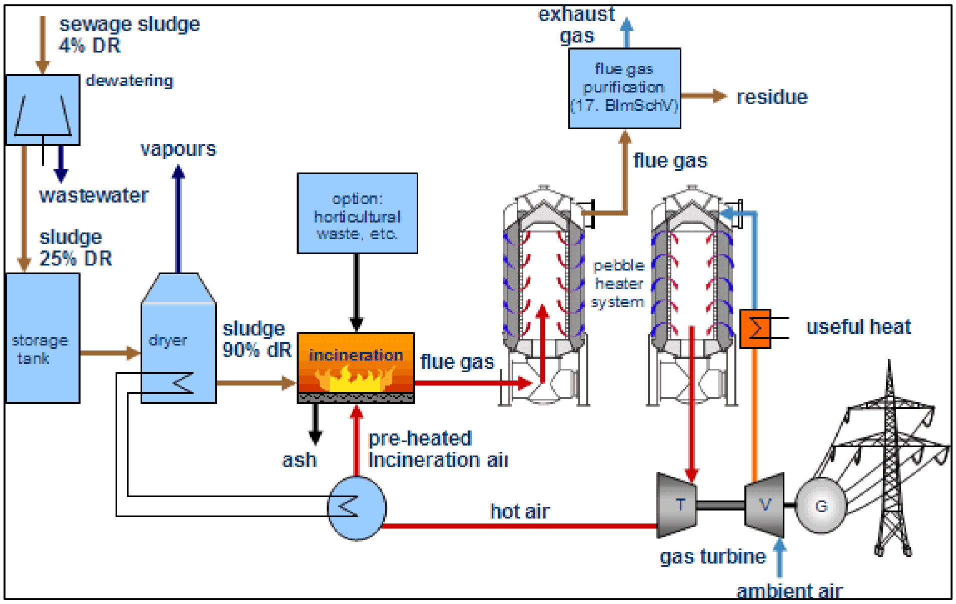

Figure 4. Incineration process

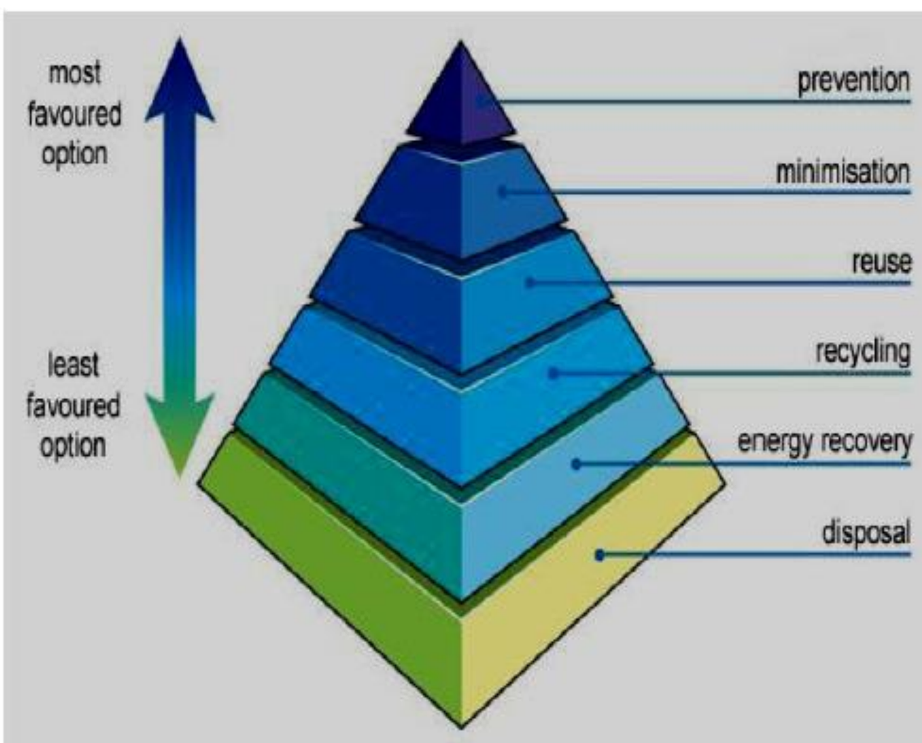

Figure 5. Most appropriate methods for sludge treatment (Kumar et al., 2017)

Table 4
Details of sludge treatment processes (COW, 2021)

Sludge treatment stage	**Principal purpose of sludge treatment stage**	**Sludge treatment process**	**Specific purpose of treatment process**	**Classification by type of treatment**
Thickening	To thicken sludge to reduce volumetric capacity of subsequent treatment and improve performance of stabilisation processes	Gravity thickening		Physical
		Elutriation	Improves gravity thickening	Physical
		Flotation		Physical
		Centrifuging		Physical
Stabilisation	To reduce organic solids content of sludge and thus reduce unpleasant odours when sludge disposed of or recycled; to reduce pathogens; to render sludge more readily dewatered	Anaerobic digestion (unheated)		Biological
		Anaerobic digestion (heated)		Biological
		Secondary digestion (unheated)		Biological
		Aerobic digestion		Biological
		Chemical stabilisation		Chemical
		Pasteurisation	Destroy pathogens	Physical
		Composting	Agricultural reuse	Biological/ Physical
Dewatering	To reduce volume of sludge to be disposed of; to render sludge easier to transport and mechanically handle; to reduce fuel used in drying or incineration processes	Drying beds	Sludge solids more than 45 %	Physical
		Belt presses	Sludge solids - 1 to 25 %	Chemical/ Physical
		Centrifuges	Sludge solids - 1 to 25 %	Chemical /Physical
		Plate presses	Sludge solids - 2 to 40 %	Chemical/ Physical
		Vacuum filters	Sludge solids - 1 to 20 %	Chemical/ Physical
Drying/Incineration	To considerably reduce volume prior to disposal	Thermal drying	Sludge solids lower than 20 %	Physical
		Incineration	Produces inorganic ash	Physical
Disposal	Safe disposal if reuse not possible	Sanitary landfill		Physical
Reuse/ Recycling	Alternatives to disposal of sludge by obtaining some beneficial use from sludge	Agriculture	Improves soil and productivity	
		Vitrification	Inert end product	Physical

Table 4 Continued
Details of sludge treatment processes (COW, 2021)

Sludge treatment stage	Principal purpose of sludge treatment stage	Sludge treatment process	Specific purpose of treatment process	Classification by type of treatment
		Oil from sludge	Product with fuel value	Physical
		Gasification	Product with fuel value	Physical

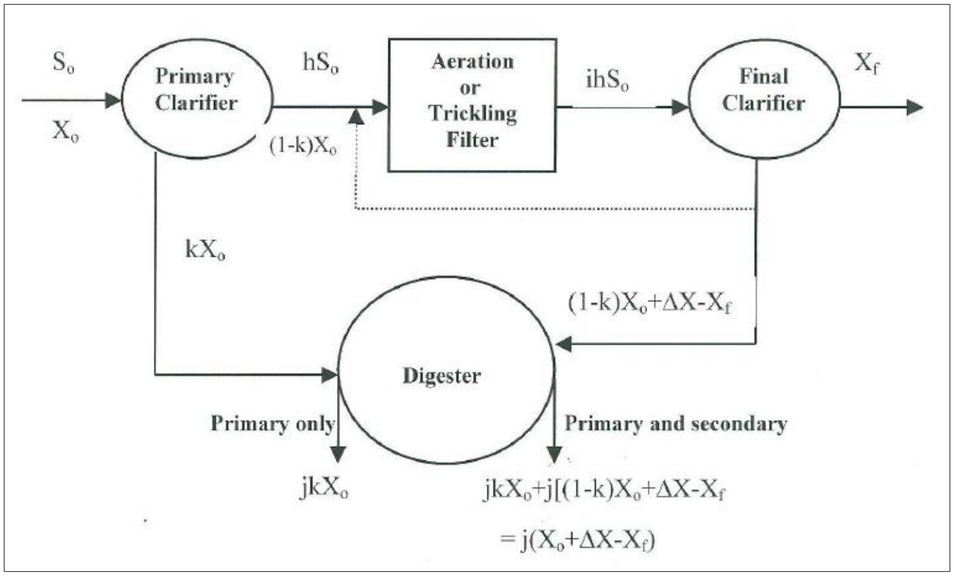

Figure 6. Details of the typical sludge quantities in wastewater treatment plant (http://www.eea.europa.eu/publications/GH-10-97-106-EN-C)

In order to determine the typical wastewater sludge in water treatment plant, the following description and terms should be known:

- S_o is influent BOD (mg/L);
- X_o is influent suspended solids (Kg/hr);
- h is fraction of BOD not removed in the primary clarifier;
- i is fraction of BOD not removed in the aeration tank;
- X_f plant effluent suspended solids (Kg/hr);
- k is fraction of X_o removed in the primary clarifier;
- j is fraction of solids not destroyed in digester;
- ΔX represents net solids produced by biological action (Kg/hr);
- Y is Yield = $\Delta X / \Delta S$; and
- $\Delta S = h\ S_o - ih\ S_o$.

Common sludge treatment processes are shown in Table 5.

Table 5
Common sludge treatment processes (EEA, 1998)

No.	Treatment process	Reason for importance
1	Sludge degritting	to apply centrifugal forces in a fluid system.
2	Dewatering	for reducing the moisture content of the sludge.
3	Drying	to make the water content suitable for processing the sludge or fertilizer.
4	Drying lagoons	The sludge drying lagoons, which are suitable only for digested sludge treatment,
5	Filtration	Vacuum filtration is used for dewatering water from raw and digested wastewater sludge.
6	Stabilization	Sludge is stabilized to reduce its pathogenic content, to remove irritating odors from the surface, and to reduce or eliminate the potential for imperfections.
7	Blending	to form a uniform blend.
8	Thickening	For increasing the solids content of the sludge.
9	Conditioning	to improve its dewatering characteristics.
10	Chemical precipitation	to remove metal ions.

Table 5 Continued
Common sludge treatment processes (EEA, 1998)

No.	Treatment process	Reason for importance
11	Heat treatment	For heating in a pressure vessel.
12	Composting	it is to stabilize biodegradable organic matter, to destroy pathogenic organisms, and also to reduce the volume/amount of waste.
13	Anaerobic digestion	The process involves the anaerobic reduction of the organic material with biological activity in the sludge.
14	Sludge digestion	In this stage the organic solids are decomposed into three types of sludge: primary sludge, secondary sludge, and digested settled sludge.
15	Aerobic digestion	the anaerobic reduction of the organic substance with biological activity in the sludge.
16	Reuse as fertilizer	It is used to make fertilizer.
17	Activated sludge	the activated sludge process is oxidation of organic substances
18	Sulfur removal	When sludge contains high amounts of sulfur compounds, problems may occur in operating such anaerobic digestion process. Sulfide may inhibit the methane formation, and it also forms hydrogen sulfide gas which is toxic and corrosive.
19	Cement production	It can be used as a for cement in production.

5. Sludge products

The produced sludge can be used as composting material, construction material (bricks and cement and road pavement), fuel and biogas, soil amendment, and in agriculture (Kumar et al., 2017). Figure 7 and 8 illustrate sludge products. Pöykiö et al. (2019) published research on using sludge as soil improver and fertilizer product.

A list of sludge handling and treatment steps and disposal/reuse paths is set out in Figure 8. All wash waters and liquors formed in the course of cleaning (e.g. sand filter backwashing) and dewatering (e.g. dewatering of sludge) must be returned to the works inlet; in no circumstances may they be discharged into a nearby watercourse owing to the fact that they contain high concentrates of polluting materials (COW, 2021).

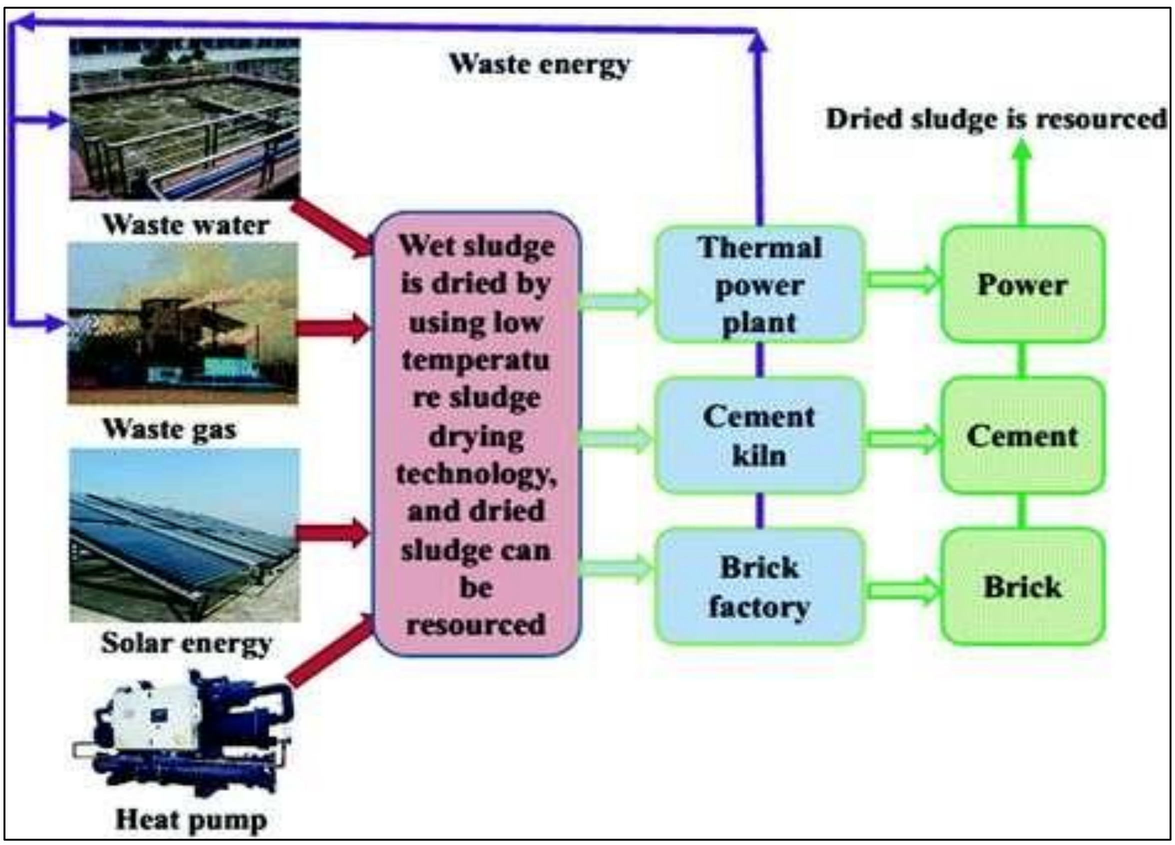

Figure 7. Sludge products

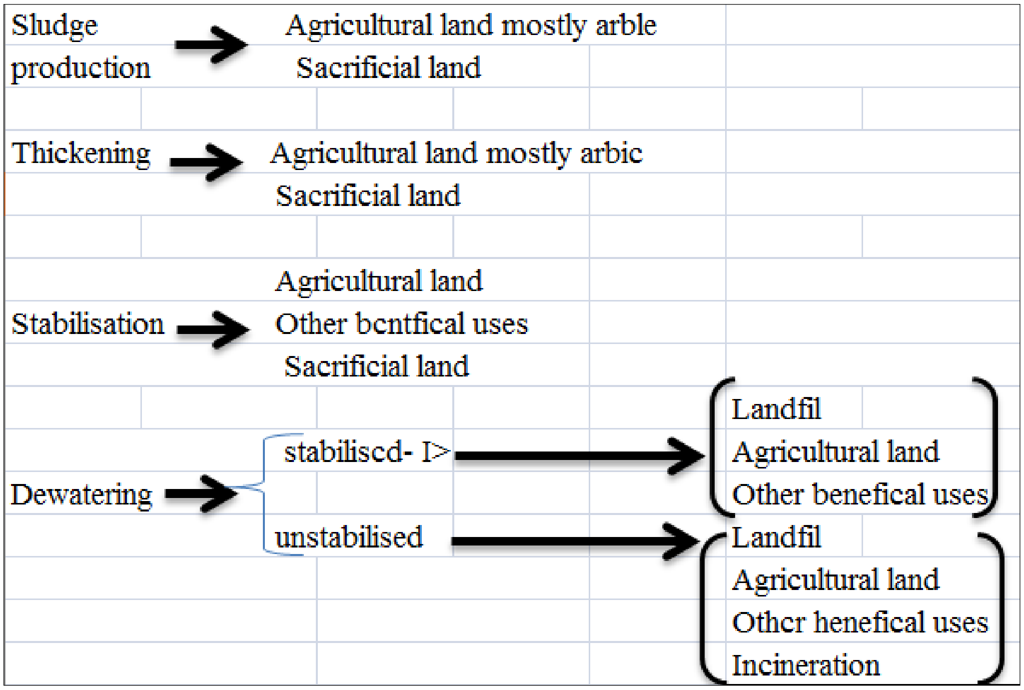

Figure 8. Principal sludge treatment and disposal routes (EEA, 1998)

6. Sludge to energy

Sludge to energy processes are shown in Figures 9 to 10. Furthermore, biogas production in several countries is illustrated in Table 6. Biogas production in several countries is documented in Table 7.

Usually, one of the most common waste management issues is wastewater sludge, which directly impacts the sources that can cause damage global environment. For this reason, it is required to minimize those wastes, and it can be used as an-alternative source of power and energy generation in the area. Nowadays, most of the countries focus on the energy production.

Using anaerobic digestion to provide energy from both types of wastewater sludge can obtain low-cost fuels compared with natural gas (Vatachi, 2019). On the other hand, Kurniawan et al. (2018) conducted a research on the wastewater sludge and then converted it to energy.

Oladejo et al. (2018) studied sludge converting to energy. Quansah et al. (2018) published a study on sludge wastewater management via conventional wastewater treatment process. Vatachi (2019) presented a study on converting sludge of the wastewater to energy.

Đurđević et al. (2020) investigated sewage sludge treatment by using the thermal and Analytical Hierarchy.

The study of Bora et al. (2020) presented producing energy from sludge.

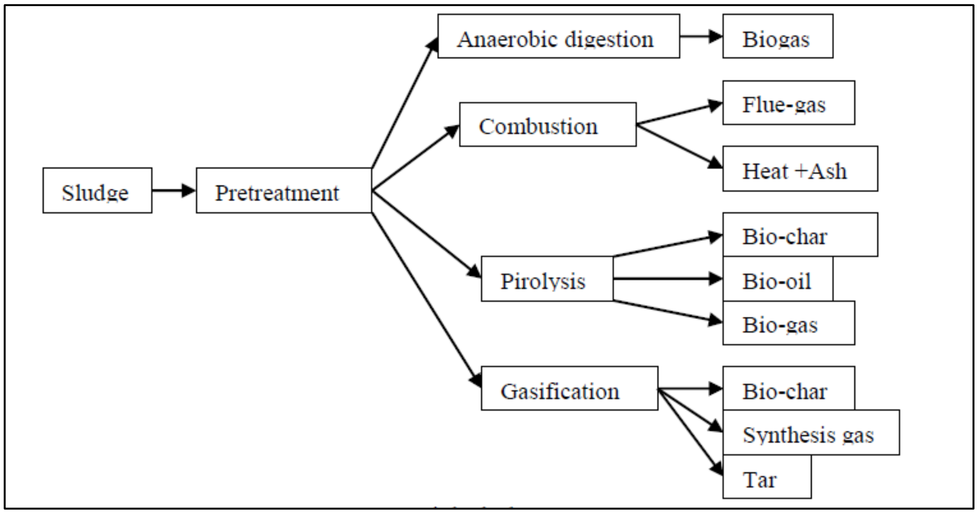

Figure 9. Potential Sludge-to-Energy Recovery Routes (Vatachi, 2019)

Table 6
Fuel types, emission and residue (Kurniawan et al., 2018)

No.	Technology	Feedstock	Feel Types	Energy Content Calorific Value	Emissions/ Residues
1	Pyrolysis	Mixed Sludge	Gas, liquid	High GCV 29.9 MJ Nm-3	NO, CO_2, CO
		Oil Sludge		35.8 MI Nni-3	Combustible gases
2	Fast Pyrolysis	rice waste and sewage sludge	Gas, Bio-oil	N/A	Char/solid
3	Fast Pyrolysis	sewage sludge	Liquid	HHV/NET Bio-oil 23.9 - 279 MJ/kg	Ash (57.9 - 75.1 wt)
4	Pyrolysis	Domestic, Commercial, Industry sludge	Gas, Liquid	(GCV at 550 °C) commercial: 825 kJ/kg: domestic. 660 kJ/kg industrial: 370 kJ/kg	syngas (CO, CO_2, CH_4, C_2H_4, and H_2)
5	Pyrolysis	Wet wastewater sludge	Syngas	HHV = 24,000 J/kg	C_2H_4, C_2H_6, C_3H_6, C_3H_8
	Gasification		Gas	HHV17500 19,500 J/kg	
6	Pyrolysis	Wastewater Biosolids	Py-gas Py-oil	2.1 MJ/ kg - 3 MJ/ kg feed biosolids	CH_4, CO_2
7	Fast Pyrolysis	Domestic WWTP	Liquid	N/A	Ash, HCs, N_2, CO_2
8	Co- gasification	Woody biomass and sewage sludge	Py-gas, Py-oil	4.5 MJ/Nm^3 (LHV average)	non condensable gas, char
9	Co- pelletization	Municipal	Py-gas Py-oil	8.43 kj/L	non condensable gas, char
10	Pyrolysis - Torrefaction	Digested (municipal)	Py-gas, Py-oil	HHV Char 25 - 30 MJ/kg JJV Liquid 41 - 43 MJ/kg	CO_2. non condensable gas, char
11	Pyrolysis	Municipal	Py-gas. Py-oil	1,934 ± 580 to 2,721 ± 321 K cal./m^3(NTP)	Non-condensable gas

Table 7
Biogas production in several countries (Hanum et al., 2019)

County	Year	Total biogas production (From agricultural residues, industry wastewater, bio-waste, landfills and sewage sludge		Biogas production in WWTPs (Only form sewage sludge)	
		Number or plants	[GWh/y]	Number or plants	[GWh/y]
Australia	2017	242	1,587	52	361
Austria	2017	291	3,489	39	18
Argentine	2016	62	n.a	n.a	n.a
Belgium	2015	184	956	n.a.	n.a
Brazil	2016	165	5219	10	210
China	2014	11,500	90	2630	n.a
Czech Republic	2015	554	2,611	n.a.	n.a
Denmark	2015	156	1,763	62	281
Filand	2015	88	623	16	152
France	2017	687	3527	88	442
Germany	2016	10,431	55,108	1258	3,517
India	2015	83,540	22,140	n.a.	n.a
Ireland	2015	28	202	n.a	n.a
Italy	2015	1,491	8212	n.a.	n.a
Japan	2015	n.a.	30,200	2,200	n.a
Norway	2017	39	738	24	223
Korea	2016	110	2,798	49	1,234
Pakistan	2015	4,000	n.a	n.a.	n.a
Poland	2015	277	906	n.a.	n.a
Switzerland	2017	634	1,409	475	620
Spain	2015	39	962	n.a.	n.a
Sweden	2017	279	1,200	139	n.a
Sri LanKa	2013	6,000	n.a	n.a	n.a
Thailand	2014	n.a.	1,500	n.a.	n.a
Netherlands	2015	268	3,011	80	541
United Kingdom	2016	967	26,457	162	950
United States	2017	2,100	1,030	1,240	n.a
Malaysia	2017	n.a.	482	35	247

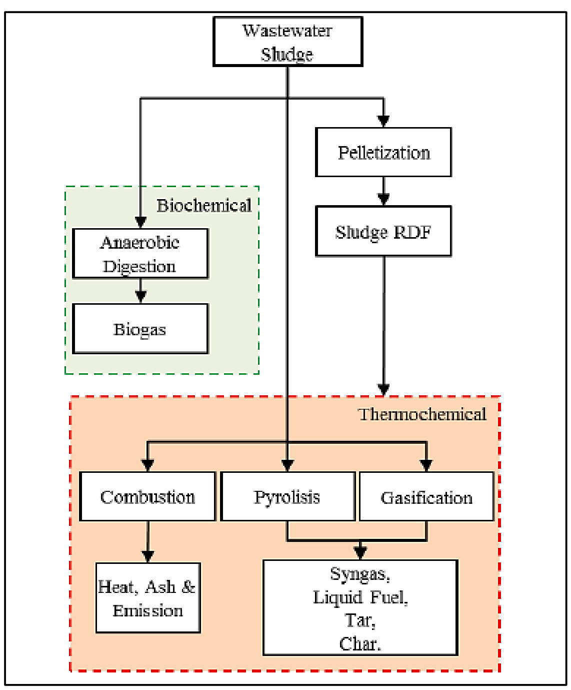

Figure 10. Routes for sludge energy recovery (Kurniawan et al., 2018)

According to Mills et al. (2014), the United Kingdom water industry generates about 800 GWhpa of electrical energy from the sewage sludge. Traditionally energy recovery from sewage sludge features anaerobic digestion with biogas utilization in combined both heat and power systems. However, based on Geng et al. (2007), sludge and primary sludge, including 20 % of the secondary sludge from a paper mill, were characterized as suitability for the producing of medium density fiberboard. On the other hand, Ayoub et al. (2016) presented in their study that the sewage treatment plant can be used with reducing the capital costs by 26 % and running costs by about 20 %. The electricity can be produced from anaerobic digestion of sewage sludge as well.

Quansah et al. (2018) suggested that the on-site sanitation and centralized facility fecal sludge treatment techniques and management practices were deemed as the core basis of study. Furthermore, the study described anaerobic and aerobic phosphorous removal process (A/O) that wasselected as an efficient and cost-effective centralized facility sludge treatment technique.

7. Estimation of sludge amount

7.1. Sludge mass calculation

If a coagulation of a treatment plant with a flow rate of ($0.5 m^3$/sec) has the dosage of alum (23.0 mg/L), without adding other chemical materials, and the concentration of the raw water suspended solids is 37.0 mg/L, and the suspended solids concentration of the effluent is 12 mg/L, the amount of the sludge mass for each day can be determined in the following way:

- Given data:

Flow rate Q= 0.5 m^3/s
Concentration of Alum C_{in1}=23.0 mg/L
Concentration of Suspended Solids C_{in2}=37.0 mg/L
Concentration of Alum C_{out}=12.0 mg/L

- Obtaining the mass of sludge using Applying Mass Balance for steady state case, Figure 11:

Mass in - Mass out = Accumulation [for Steady state case in = out]
Mass in = Mass out
Q · Cin1=23.0 mg/L + Q · Cin2 = 37.0 mg/L= Q · C out = 12.0 mg/L + Mass Sludge
Mass of sludge = Q · (Cin1 + Cin2 - C out)
Mass of sludge = 0.5 m^3/s · (23.0 mg/L + 37.0 mg/L - 12.0 mg/L)
Mass of sludge = 24 m^3/s. mg/L (1,000 L/m^3) · (86,400 sec/day)
Mass of sludge = 2,073,600,000 mg/day (g/1,000 mg) · (kg/1,000 g)
Mass of sludge = 2,073.6 kg/day

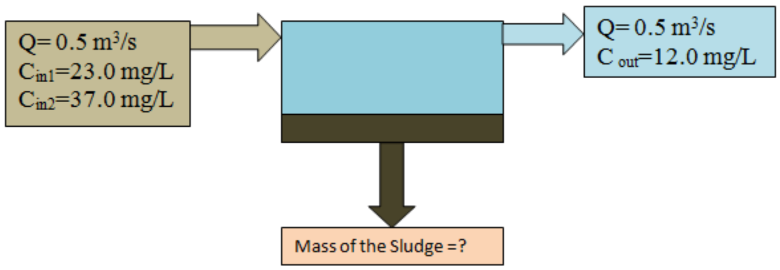

Figure 11. Details of produced sludge mass

7.2. Estimation of influent Sludge

The example is taken from Andreoli et al. (2007), for the conventional WWTP with anaerobic digestion of the mixed sludge, the number of the population is 67,000 inhabitants, and the size of the centrifuges for the dewatering of the sludge, the amount of the influent to the dewatering unit effluent form secondary digester is 46.9 m^3/day. To determine the maximum influent sludge flow per hour:

Q_{avg}= 46.9 m^3/day = 1.95 m^3/hr
Qmax= 1.5 (peak factor) · 1.95 m^3/hr= 2.93 m^3/hr

To select the equipment such as centrifuge, the maximum sludge flow that will be dewatered and 6 m^3/hr is selected (one as operating and the another one as a spare unit).

The following operating hour can be selected based on the equation below:

$$\text{Operating time}\left(\frac{\text{hr}}{\text{day}}\right)=\frac{\text{Average influent sludge flow}\left(\frac{m^3}{\text{day}}\right)}{\text{Number of units}\cdot\text{Unitary capacity}\left(\frac{m^3}{\text{hr}}\right)}=\frac{46.9\ m^3/\text{day}}{1\cdot 6\ m^3/\text{day}}=8\ \text{hr/day}$$

8. Produced fuel

The subject is vital, especially for those areas that have a lack of waste management due to the financial and economic issues. Therefore, this research aimed to present the main existing problems and at the same time the methods of sludge treatment. The research can be used as an investigation reference for future challenges of energy production and also as a source of a big infrastructure and income for the current city and for the similar areas. Due to various sludge characteristics, it has proved that the presence of organic matter in sludge composition can be the basic source for future energy challenges. This energy requires the proper managing and conserving.

Normally, the wastewater sludge contains high quantities of the organic materials, and based on this, the value of the dry sludge can range within (10,000- 20,000 kJ/kg) based on (Vatachi, 2019), and the fuel value of house coal, crude oil and LPG is given below:

House coal: 27,000 - 31,000 kJ/kg
Heating oil: 42,500 kJ/kg
Butane and propane (LPG): 46,300 kJ/kg.

9. Calculation of sludge amount and Energy in Erbil City

Currently there is no central WWTP in Erbil City. Small size WWTPs are available in some investment residential projects and other locations such as Awamedica Pharmaceutical Company, Italy 2 Project, Green Land Project, Cihan City, and Rami Towers etc. Aziz (2020) reported that quantity of municipal WW at Tooraq Area is 5.56 m^3/s (480,384 m^3/d).

Population of Erbil City center is around 1,000,000 people.

Dry content of sludge per head per day = 0.05 kg/day (Singh and Singh, 2003).

Weight of dry content = 1,000, 000 · 0.05 kg/day = 50,000 kg/day

Total weight of wet sludge = 50,000 · (100/5) · 1.02 = 1,020,000 kg/day (Singh and Singh (2003) stated that for 5 kg dry weight, there is 100 kg of wet sludge with specific gravity of 1.02).

Volume of wet sludge = 1,020,000 kg/day/1,000 kg/m^3 = 1,020 m^3/day (Based on Singh and Singh (2003), density of wet sludge is 1,000 kg/m^3).

Required tank capacity = (1,020 · 100)/3 = 34,000 m^3/day (If only 3 % of fresh sludge is added to digester)

If 30 % added as margin for variations = 34,000 · (30/100) = 10,200 m^3/day

Total tank capacity = 34,000 m^3 + 10,200 m^3 = 44,200 m^3/day

Per capita volume = 44,200/1,000,000 = 0.0442 m^3/capita/day

The amount of produced gas = 1,000,000 · 0.02 m^3 = 20,000 m^3/day (volume of produced gas per capita per day is 0.02 m^3 (Singh and Singh, 2003)).

Calorific value for produced gas = 5,000 · 20,000 = 10 · 10^7 K.cal./day (If calorific value per m^3 is 5,000 K. cal.)

Calorific value become 9.5 · 10^7 K.cal./day (Based on Singh and Singh (2003), 5 % will be lost by radiation).

About 45,000 K.cal is required for one break H.P. per day with thermal efficiency of 35 %. Therefore, the gross power available from gas = 9.5 · 10^7 K.cal. /day/45,000 K.cal = 2,111.11 B.H. P.

Net power available from gas = 1,477.78 B.H. P./day (for 70 % mechanical efficiency)

The volume of the wet sludge is 1,020 m^3/day

If it is spread in a 20 cm thick layer on under drained sand beds,

The required area = 1,020 m^3/0.20 m = 5,100 m^2.

10. Conclusions

Normally, wastewater sludge contains moisture, heavy metals, organic and inorganic materials that can be used as the sources of energy. A number of techniques were offered for the wastewater sludge treatment; each method has advantages and disadvantages. Characteristics and quantity of produced sludge were presented. Several final products can be achieved from processing the sludge. The calculated amount of dry sludge in Erbil City was 50,000 kg/d which resulted in produced calorific value of 9.5 · 10^7 K. cal./day. Additionally, the required area for under drain sand bed area was 5,100 m^2.

References

Amin K. N., Aziz S. Q., Feasibility of Erbil wastewater reuse for irrigation, Zanco Journal of Pure and Applied Sciences, 17, 2005, 63-77,

Amudha V., Kavitha S., Fernandez C., Adishkumar S., Banu J. R., Effect of deflocculation on the efficiency of sludge reduction by Fenton process, Environmental Science and Pollution Research, 23 (19), 2016, 19281-19291,

Andreoli C. V., Von Sperling M., Fernandes F., Sludge Treatment and disposal, Volume six, Biological wastewater treatment serious, IWA, 2007, 256,

Asia I. O., Enweani I.B., Eguavoen, I. O., Characterization and treatment of sludge from the petroleum industry, African Journal of Biotechnology, 5 (5), 2006, 461-466,

Atienza-Martínez M., Mastral, J.F., Ábrego J., Ceamanos J., Gea, G., Sewage sludge torrefaction in an auger reactor, Energy and Fuels, 29 (1), 2015, 160-170,

Ayoub M., Rashed I. G. A. A., El-Morsy A., Energy production from sewage sludge in a proposed wastewater treatment plant, Civil Engineering Journal, 2 (12), 2016, 637-645,

Aziz S. Q., Variation of Erbil Municipal Wastewater Characteristics Throughout 26 Years (1994-2020) with Possible Treatments and Reusing: A Review. 3rd International Conference on Recent Innovations in Engineering, Materials Science and Engineering, 978, July 2020, 012044,

Aziz S. Q., Ali S. M., Characteristics and Potential Treatment Technologies for Different Kinds of Wastewaters, Zanco Journal of Pure and Applied Science, 30 (1), 2018, 122-134,

Aziz S. Q., Aziz H. A., Yusoff M. S., Mohajeri, S., Removal of phenols and other pollutants from different landfill leachates using powdered activated carbon supplemented SBR technology, Environmental monitoring and assessment, 184 (10), 2012, 6147-6158,

Aziz S. Q., Omar I. A., Bashir M. J. K., Mojiri A., Stage by stage design for primary, conventional activated sludge, SBR and MBBR units for residential wastewater treatment and reusing, Advances in Environmental Research, 9, 2020, 233-249,

Aziz S. Q., Seasonal Variation of Some Physical and Chemical Properties of Water and Wastewater in Erbil City, Journal of Dohuk University, 7 (2), 2004, 76-88,

Bapeer U. H., A study on the main sewage channel in Erbil city Destiny and its matching to irrigation purpose, Journal of Kirkuk University-Scientific Studies, 5 (2), 2010, 61-75,

Bora R. R., Richardson R. E., You F., Resource recovery and waste-to-energy from wastewater sludge via thermochemical conversion technologies in support of circular economy: a comprehensive review, BMC Chemical Engineering, 2 (1), 2020, 1-16,

Chiou J., Wu I.T., Evaluating the manufacturability and combustion behaviors of sludge-derived fuel briquettes, Waste Management, 34 (10), 2014, 1847-1852,

City of Windhoek (COW), 50 Years of Direct Potable Reuse - The Windhoek Experience, http://documents.windhoekcc.org.na/Content/Documents/CoW50yrDPR/Day%201%20-%20PDF/1.%20DPR%2050%20Year%20History%20-%20PvR.pdf, overtaken: 22.09.2021,

CORE, 2022, https://core.ac.uk/, [Accessed September 22, 2021],

De Azevedo A. R., Alexandre J., Pessanha L. S. P. da S. T. Manhães R., de Brito, J., Marvila, M.T., Characterizing the paper industry sludge for environmentally-safe disposal, Waste Management, 95, 2019, 43-52,

Degaard Paulsrud B., Karlsson, I., Wastewater sludge as a resource: Sludge disposal strategies and corresponding treatment technologies aimed at sustainable handling of wastewater sludge, Water Science and Technology, 2002, 46 (10), 2002, 295-303,

Demirbas A., Edris G., Alalayah W. M., Sludge production from municipal wastewater treatment in sewage treatment plant, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 39 (10), 2017, 999-1006,

Dempsey B. A., Jeon B. H., Characteristics of sludge produced from passive treatment of mine drainage, Geochemistry Exploration Environment Analysis, 1(1), 2001, 89-94,

Đurđević D., Trstenjak M., Hulenić I., Sewage sludge thermal treatment technology selection by utilizing the analytical hierarchy process, Water, 12 (5), 2020, 1255,

EEA, Urban Wastewater Projects - A Layperson's Guide, Wastewater and Sludge Treatment and Disposal, Chapter Six, 1998, 124,

Folgueras M. B., Alonso M., Díaz R. M., Influence of sewage sludge treatment on pyrolysis and combustion of dry sludge, Energy, 55, 2013, 426-435,

Fonts I., Azuara M., Gea G., Murillo M. B., Study of the pyrolysis liquids obtained from different sewage sludge, Journal of analytical and applied pyrolysis, 85 (1-2), 2009,184-191,

Geng X., Zhang S. Y., Deng J., Characteristics of paper mill sludge and its utilization for the manufacture of medium density fiberboard, Wood and Fiber Science, 39(2), 2007, 345-351,

Guo Z. Sun Y., Pan S.Y., Chiang P.C., Integration of Green Energy and Advanced Energy-Efficient Technologies for Municipal Wastewater Treatment Plants, A review, International Journal of Environmental Research and Public Health, 16 (7), 2019, 1282,

Hanum F., Yuan L. C., Kamahara H., Aziz H. A. Atsuta Y., Yamada T., Daimon H., Treatment of Sewage Sludge Using Anaerobic Digestion in Malaysia: Current State and Challenges, Frontiers in Energy Research, 7, 2019, 1-7,

http://neoakruthi.com/blog/sewage-treatment-plant-for-hotels.html [Accessed April 28, 2021],

http://www.eea.europa.eu/publications/GH-10-97-106-EN-C [Accessed August 27, 2021],

Janczukowicz W., Szewczyk M., Krzemieniewski M., Pesta J., Settling Properties of Activated Sludge from a Sequencing Batch Reactor (SBR), Polish Journal of Environmental Studies, 10, (1), 2001, 15-20,

Johnson O. A., Napiah M., Kamaruddin I., Potential uses of waste sludge in construction industry: a review, Research Journal of Applied Sciences, Engineering and Technology, 8 (4), 2014, 565-570,

Karagiannidis A., Samaras P., Kasampalis T., Perkoulidis G., Ziogas P., Zorpas A., Evaluation of sewage sludge production and utilization in Greece in the frame of integrated energy recovery, Desalination and Water Treatment, 33 (1-3), 2011,185-193,

Kim H. J., You J. Y., Park, C. J., Review of sewage and sewage sludge treatment in Korea, International Proceeding of Chemical, Biological and Environmental Engineering, 101, 2017, 67-73,

Kollmann R., Neugebauer G., Kretschmer F., Truger B., Kindermann H., Stoeglehner G., Ertl T., Narodoslawsky M., Renewable energy from wastewater-Practical aspects of integrating a wastewater treatment plant into local energy supply concepts, Journal of Cleaner Production, 155, 2017, 119-129,

Kumar V., Chopra A. K., Kumar A., A review on sewage sludge (Biosolids) a resource for sustainable agriculture, Archives of Agriculture and Environmental Science 2 (4), 2017, 340-347,

Kupka T., Mancini M., Irmer M., Weber R., Investigation of ash deposit formation during co-firing of coal with sewage sludge, saw-dust and refuse derived fuel. Fuel, 87 (12), 2008, 2824-2837,

Kurniawan T., Hakiki R., Sidjabat F.M., Wastewater sludge as an alternative energy resource: A review, Journal of Environmental Engineering and Waste Management, 3 (1), 2018,1-12,

Li J., Ding L.B., Cai A., Huang G. X., Horn H., Aerobic sludge granulation in a full-scale sequencing batch reactor, BioMed research international, 2014, 268789,

Magdziarz A., Werle S., Analysis of the combustion and pyrolysis of dried sewage sludge by TGA and MS, Waste management, 34 (1), 2014, 174-179,

Manara P., Zabaniotou A., Towards sewage sludge based biofuels via thermochemical conversion-A review, Renewable and Sustainable Energy Reviews, 16 (5), 2012, 2566-2582,

Mesdaghinia A. R., Akhavan M. P., Vaezi F., Naddafi K., Moosavi G. H., Waste sludge characteristics of a wastewater treatment plant compared with environmental standards, Iranian Journal of Public Health, 33(1), 2004,5-9,

Metcalf and Eddy, AECOM, Wastewater Engineering: Treatment, Disposal and Reuse, 5th Edition, McGraw Hill, New York, 2014, ISBN: 978-0073401188, 2048

Mills N., Pearce P., Farrow J., Thorpe R. B., Kirkby N. F., Environmental and economic life cycle assessment of current and future sewage sludge to energy technologies, Waste management, 34 (1), 2014, 185-195,

Nei L., Haiba E., Kutti S., Kipper K., Herodes K., Lillenberg M., Sewage sludge compost, microbial activity and pharmaceuticals. Global Journal on Advances Pure and Applied Sciences, 3 (3), 2014, 30-37,

Oladejo J., Shi K., Luo X., Yang G., Wu T., A review of sludge-to-energy recovery methods, Energies, 12 (1), 2018, 1-38,

Pöykiö R., Watkins G., Dahl O., Characterization of municipal sewage sludge as a soil improver and a fertilizer product, Ecological Chemistry and Engineering, 26 (3), 2019, 547-557,

Qian L., Wang S., Xu D., Guo Y., Tang X., Wang L., Treatment of municipal sewage sludge in supercritical water: a review, Water research, 89, 2016,118-131,

Quansah A., Ntaryamira T., Rwemera, J., Sludge wastewater management by conventional treatment process: case study-Bujumbura municipal sewage, International Journal of Sciences, 4, 2018, 52-65,

Salama Y., Salama O., Chennaoui M., Mountadar M., Study of dysfunction into activated sludge basins in sewage treatment plant of the City of Khouribga (Morocco), Journal of Materials and Environmental Science, 11 (6), 2020, 922-942,

Shekha Y. A., Haydar H. A., Al-Barzingy Y. O. M., The effect of wastewater disposal on the water quality and phytoplankton in Erbil wastewater channel, Baghdad Science Journal, 7 (2), 2010, 984-993,

Sievers M., Ried A., Koll R., Sludge treatment by ozonation Ð evaluation of full-scale results, Water Science and Technology, 49(4), 2004, 247-253,

Singh G., Singh J, Water Supply and Sanitary Engineering (Environmental Engineering), Sixth edition, Standard Publishers Distributers, 2003, 968, ISBN 81-8014-029-6,

Uygur A., Kargi F., Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor, Journal of environmental management, 71 (1), 2004, 9-14,

Vatachi N., Wastewater sludge to energy production. A review, IOP Conference Series: Material Science and Engineering 595, 2019, 012053,

Yan S., Subramanian S. B., Tyagi R. D., Surampalli R. Y., Sustainable sludge management, Chapter 2: Wastewater Sludge Characteristics, 2009, 6-36.

Karakteristike taloga iz otpadnih voda, tehnike obrade i proizvodnja energije

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INFORMACIJE O RADU

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Ključne reči:
Odlike
Energija
Erbil
Talog
Obrada
Otpadne vode

I Z V O D

Ovo istraživanje predstavlja pregled vrsta taloga, njegove odlike, kao i metode obrade koje se koriste. Pored toga, proučavan je i talog kao potencijalni izvor energije. Rad se uglavnom fokusira na analizu različitih odlika taloga na osnovu prethodnih istraživanja. Analiziran je talog iz otpadnih voda nastao prilikom primarne, sekundarne i tercijarne obrade. On se uglavnom sastojao od mnogih organskih i neorganskih materijala. Neki od materijala su uklonjeni putem fizičkog postupka, dok su drugi zahtevali hemijski i biološki postupak. Talog je bio u čvrstom ili polu čvrstom stanju, kao i u obliku mulja koji je sadržao štetne supstance u vidu proteina, fenola i opasnih materijala. U radu su takođe prikazane različite metode proizvodnje energije. Na kraju se došlo do zaključka da bi svaka vrsta taloga mogla proizvesti energiju i biti osnovni finansijski proizvod za odabrano područje, a u isto vreme očuvati životnu sredinu. Izračunata je količina isušenog taloga za 1.000.000 stanovnika u Erbilu, Kurdistan, Irak, i iznosila je 50.000 kg/d, a dobijena toplotna vrednost je iznosila $9{,}5 \cdot 10^7$ Kcal/d. Pored toga, osnovna površina korita ispod isušenog taloga iznosila je 5.100 m^2.