Energy from Domestic Wastewater and Recovering the Potential Energy of Sewage Sludge

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Abstract

This paper gives a concept overview of energy from sludge in term of anaerobic digestion method. Wastewater is grossly undervalued as a resource of energy. The sludge production is a function of the wastewater treatment system used for liquid phase. In principal, all the biological treatment process generate sludge. Nevertheless, waste and wastewater treatment have been a neglected problem in Afghanistan, where 80 % of our energy importing from neighborhood countries. As world going toward renewable energy, sewage treatment plants can retrieve valuable resources such as water, green energy and fertilizers. Developing and implementing renewable energy systems such as biogas from anaerobic digestion (AD), based on national and regional biomass resources, will increase security of national energy supply and diminish dependency on imported electricity and gases. In Afghanistan there is a lot of opportunities to capture affordable energy and heat from biomass and biogas and it enable every individual households to generate their own energy demand, but unfortunately people don not aware about this valuable resource and it is utilization. So in this study struggled to provide basic information about the value of waste and biomass and then promulgate to local people and governments to consider on their financing institutions operating in the future. Therefore, the objective of this study focused on the concept of resource efficiency in sewerage sludge to convert into green energy. The methodology was based on anaerobic process which is widely used for treatment of municipal waste sludge and has excellent potential for treatment of many industrial waste; and the design criteria are based on a volumetric organic load (kgBOD/m^3·d). In particular, calculation and simulation results from treated flow of 2000 m^3/d, resulting from amount of yielding gas is 109 m^3/d which is huge amount of capturing energy at small treatment plant. In consequence, the production of energy from sewage sludge through anaerobic digestion has been able to effectively offset energy demand for wastewater treatment plant and methane is a useful end product. Developing source of clean, renewable energy will boost local and regional economics strengthen our national energy security as well decrease our energy dependency.

Keywords: Domestic Wastewater, Sludge, and green energy.

1. Introduction

Efficient municipal wastewater treatment produces vast amounts of sludge. Sludge management is an integral part of any modern municipal wastewater treatment plan [1]. Sewage sludge generated in wastewater treatment plants, comprising primary sludge from mechanical pre-treatment as well as surplus from biological treatment, requires further treatment for a number of reasons [10]. At a time of heightened concern about waste, climate change and the need for cleaner energy; an anaerobic digestion of organic waste provides many benefits: its includes the generation of renewable energy, a reduction of greenhouse gases, a reduced dependency on fossil fuels [3]. After digestion the sludge has a much lower volatile content and the odour has changed [4]. Calorific value of biogas produced in the digesters during anaerobic stabilization amounts to approximately about 6 kWh/m^3 – this corresponds to about half of diesel oil. Likewise, generation of energy and waste heat in a combined heat and power plant, the energy needs for a typical domestic wastewater treatment plant employing aerobic activated sludge treatment and anaerobic sludge digestion is 0.6 kWh/m^3 of wastewater treated, about half of which is for electrical energy to supply air for the aeration basins [9]. With conventional approaches involving aerobic treatment a quarter to half of a plants energy needs might be satisfied by using the CH_4 biogas produced during anaerobic digestion, and other plant modifications might further reduce energy needs considerably [5]. On the other word, waste is a source of energy which is a good alternative of fossil fuel in order to mitigate the climate change and greenhouse gas emission. Production of biogas from sewage sludge is already applied worldwide on small, medium, and large scales, the reason, anaerobic digestion technology is attractive because of its role in organic waste emphasizing these benefits and implementing certain policies [7].

2. Methodology

This paper present producing energy from sewage sludge through anaerobic digestion design in wastewater treatment which is applied to the stabilization of the organic matter through the action of bacteria in contact with the sludge, in conditions that are favorable for their growth and production. The methodology of sludge digestion based on (1) solids retention time and accurate numerical calculations for the amount of flow rate methane gas, (2) volatile solids destruction, (3) and based on simulation results. Analyzing the behavior of AD systems by integrating biological processes to effectively determined biogas yield. The simulation is based on two important parameters: the COD content of the effluent wastewater and the biogas generation rate. (4) For this study, to compare the cost-effective of and benefits of plants, the flow amount of four decentralized wastewater had considered in term of treatment which currently operating individually [12].

3. Wastewater Treatment and its characteristics

The concept of domestic wastewater treatment level encompasses preliminary, primary, secondary and advanced treatment which the whole entire wastewater and sludge treatment plant and process depicted in figure 1 [2]. So the main characteristics of wastewater which present the main physical, chemical and biological characteristics of domestic sewage as a follow; for instance, (1) physical characteristics of domestic sewage are contains a number of parameters, like temperature, color, odour, and turbidity. (2) Chemical characteristics include, total suspended solids TS, volatile, dissolved, fixed, and settleable. (3) Organic matter, indirect determination, biochemical oxygen demand BOD_5, measure at 5 days, chemical oxygen demand COD, present the quantity of oxygen required to chemically stabilise the carbonaceous organic matter, and it has indirect determination total organic carbon TOC, and organism composition [8].

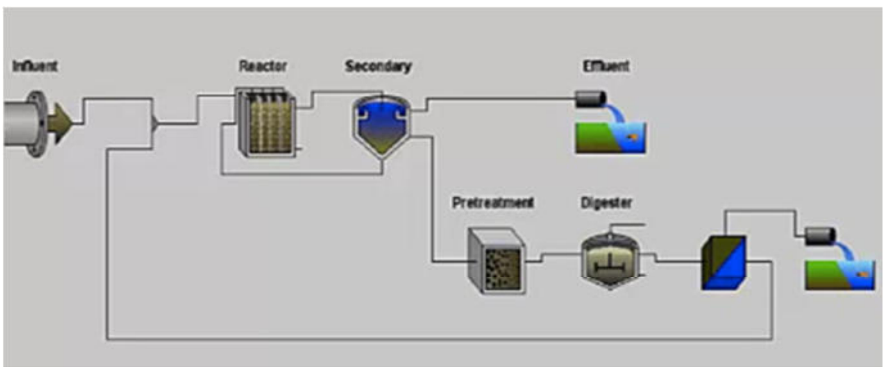

Figure 1. Schematic flow of wastewater and sludge treatment plant and process [12]

3. Sludge Characteristics

In biological wastewater treatment, part of the chemical oxygen demand COD removed into biomass, which will make up the biological sludge [5]. Knowledge of the characteristics of sludge, along with the quantities produced, is important for the design of sludge processing system in a wastewater treatment plant [8]. Originating from the treatment process of wastewater, is the residue generated during the primary (physical and/or chemical), the secondary (biological) and the tertiary treatment. The source of solids in a treatment plant vary according to the type of plant and its method operation. Obviously, in order to treat and dispose of the sludge that is produced in a wastewater plant effectively, it is crucial to know the characteristics of the sludge that will be processed [2, 6]. Table 1 presents, for the sake of simplicity, the mass of suspended solids waste per unit of applied COD or influent COD, considering typical efficiencies of COD removal wastewater treatment processes. For instance, in the activated sludge process – extended aeration each kilogram of COD influent to the biological stage generates 0.5 to 0.55 kg of suspended solids. In addition, every inhabitant produce approximately 100 gCOD/day per capita [5].

Table 1. Characteristics of primary sludge and activated sludge [2, 6].

Item/Sludge	**Primary Sludge**	**Activated Sludge**	**Composition**
Total dry Solids (total solids, TS)%	5 – 9	0.8 – 1.2	• Non-toxic organic carbon compounds (appx. 60% on dry basis), Kjeldhal-N, phosphorous
Volatile solids, VS (% of TS)	60 – 80	59 – 88	

Grease and fates (% TS)	7 - 35	5 - 12	containing components.
Protein (%of TS)	20 – 30	-	• Toxic pollutants: heavy metals (Zn, Pb, Cu, Cr, Ni, Cd, Hg, As: Concentration vary from 1000 mg/L to less than 1 mg/L.), polychlorinated biphenyls (PCB), PAH, Dioxins, Pesticides, Endocrine disrupters, Nony1-phenols.
Nitrogen (N, % of TS)	1.5 – 4	2.4 – 5.0	
Phosphorus (P2O5, % of TS)	0.8 – 2.8	2.8 – 11	
Potash (K2O, % if TS)	0 – 1	0.5 – 0.7	
Cellulose (% of TS)	8 – 15	-	
Iron (not as sulfide)	2.0 – 4.0	-	
Silica (SiO2, % of TS)	15 – 20	6.5 – 8.0	
pH	5.0 – 8.0	6.5 – 8.0	• Pathogens and other microbiological pollutants.
Alkalinity (mg/L as CaCO3)	500 - 1500	580 – 1100	
Organic acids (mg/L as HAc)	200 - 2000	1100 – 1700	• Inorganic compounds: Silicates, aluminates, calcium and magnesium containing compounds.
Energy content, kJ/kg TSS	23,000-29,000	19,000-23,000	

4. Energy and resource recovery

4.1 Biogas recovery by anaerobic digestion

There are many sludge derived resource recovery options including recovery of biogas, fuel gas, electricity generation production of construction material, nutrient recovery, biofuel recovery etc. among the above mentioned methods, anaerobic digestion is the most popular sludge stabilization technology currently more practicing in the world [4]. Anaerobic digestion (AD) is the biological degradation of complex organic substances in the absence of oxygen. During these reactions, energy is released and much of the organic matter is converted to methane, carbon dioxide, and water [5]. Currently, sludge stabilization by anaerobic digestion is used extensively of municipal wastewater sludge. High rate of anaerobic digestion slightly depend upon sludge type, mesophilic digestion and thermophilic digestion in term of treatment, for instance chemical sludge have been successfully digested anaerobically, although in several cases, volatile solids reduction and gas production were low, compared with conventional sewerage sludges. Anaerobic digestion is a feasible stabilization method for wastewater sludges that have low concentrations of toxins and a volatile solids content above 50 percent. Consequently, AD offers several advantages over other methods of sludge stabilization, specifically, the process: produce methane, a usable source of energy. Surplus methane is frequently used for heating buildings, running engines, or generating electricity; reduces total sludge mass through the conversion of organic matter to primarily methane, carbon dioxide, and water. Commonly, 25 to 45 % of the raw sludge solids are destroyed during AD; Yields a solids residue suitable for use as a soil conditioner; and inactivates of pathogens [2].

4.2. Anaerobic Digester Gas Design Assumptions

To review briefly, considering the primary treatment plant designed to treat 2000 m3/d of wastewater. Check the volumetric loading and estimate the percent stabilization and the amount of gas produced per capita. Assume the quantity of dry volatile solids and biodegradable COD removed is 0.14 kg/m3 Assume that the sludge contains about 95% moisture and other pertinent design assumption are as follows:

1. The hydraulic regime of the reactor is complete-mix. 2. τ = SRT = 10 days at 35 oC. 3. Efficiency of waste utilization (solids conversion) E = 0.70. 4. Digester gas is 65 percent [2, 3]

Solution: 1. determining the daily sludge volume using following equation.

$$V = \frac{Ms}{\rho SP} \text{ ……………………… (1)}$$

Where V = volume, m3, Ms = mass of dry solids, kg ρw = specific weight of water, 10 kg/m3. Ssl = specific gravity of the sludge, Ps = percent solids expressed as a decimal.

Sludge volume = $\frac{(0.15\ kg/m3)(2{,}000\frac{m3}{d})}{1.02(1000\frac{kg}{m3})(0.05)}$ = 6 m3/d

Determine the COD loading.

COD = (0.14 kg/m3) (38,000 m3/d) = 300 kg/d

3. Compute the digester volume. $\tau = \frac{V}{Q}$ ………………………….. (2)

$$V = Q\tau = \left(6\,\frac{m3}{d}\right)(10d) = 60\ m^3$$

4. Compute the volumetric loading. $kg\ bCOD/m3 * d = \frac{(300\ kg/d)}{60m^3} = 5\ kg/m3 * d$

5. Compute the quantity of volatile solids produced per day following equation:

$$P_x = \frac{YQ(S_0 - S)\left(10^3 \frac{g}{kg}\right)}{1 + (k_d)SRT} \ldots\ldots\ldots\ldots\ldots \quad \ldots (3)$$

Where Y = yield coefficient, g VSS/g bCP, Kd = endogenous coefficient, (range from 0.02 to 0.04)
SRT = solids retention time. S0 = 280 kg/d, S = 2800(1-0.70) = 84 kg/d, S0 - S = 280 – 84 = 196 kg/d

$$P_x = \frac{(0.08)[280 - 84)kg/d]}{1 + (0.03d^{-1})(10d)} = 13\ kg/d$$

6. Compute the volume of methane produced per day at 35 ºC.

$$V_{CH4} = (0.40)\left[(So - S)(Q)/(1000\,\frac{g}{kg}) - 1.42P_x\right] \ldots\ldots\ldots\ldots (4)$$

Where: V_{CH4} = volume of methane produced at standard condition (0 ºC and 1 atm), m3/d.

$Q = flowrate, m^3/d$, S0 = bCOD in influent, mg/L , S = bCOD in effluent, mg/L,

Px = net mass of cell tissue produced, kg/d.

$V_{CH4} = (0.40\ m3/d)[(280 - 84)kg/d] - 1.42(13)]$ = 71 m3/d

So the total gas production: Total gas volume = 71/0.65 = 109.2 m3/d.

Based on the above calculations total gas production is 109 cubic meter per day, which is high amount of yielding gas that produced from anaerobic sludge digester that could be counted as a valuable amount of renewable energy from wastewater treatment.

5. Result and Discussions

5.1. Process Description:

In anaerobic treatment there are two basically different process design, Generation of digester gas is a slightly depend upon into characteristics of sludge, composition, and temperature, so yielding energy is direct result of the destruction of volatile solids as well as suspended solids. Gas from anaerobic digestion contains about 65 to 70 percent CH4 by volume, 25 to 30 percent CO2 and small amount of N2, H2, H2S, water vapor, and other gases [5, 10].

5.2. Gas Production:

BOD may be removed in anaerobic treatment by conversion of organic matter to methane gas or by separation of BOD producing bacterial cells and suspended solids from treated effluent. The volume of methane gas produced during the digestion process can be estimated using equation (4). Specific gas production for wastewater sludge generally ranges from 0.8 to 1.1 m3/kg of volatile solids destroyed [6]. Gas production can fluctuate over a wide range, depending on the volatile solids content of the sludge feed and the biological activity in the digester. Gas production can also be estimated crudely on a per capita basis, the normal yield is 15 to 22 m^3 /10^3 persons *d in primary plants treating normal domestic wastewater. In secondary treatment plants, the gas production is increased to about 28 $m^3/10^3$ Persons * d. The retention time in primary sedimentation has a direct effect on the biogas production on the other hand, higher retention time decreases the BOD load in the biological treatment. Figure 1and 2 show the composition and temperature of sludge [9].

5.3. Gas collection

The gas is collected under the cover of the digester. The cover may be floating, fixed, or membrane. Gas and air must not be allowed to mix, otherwise an explosive mixture may result as explosions have occurred in wastewater treatment plant. Biogas utilization and value, methane from anaerobic digesters is a valuable energy source. In many plants, it is used as a fuel for boiler and internal combustion engines that provide electricity or motive power for pumps, as 1 m3 biogas has an energy content of 6kWh, the daily producing biogas in this study (109 m3/24h) 654 kWh.

Thus the power is 1.6 kW (109kWh/24h), of which in a small Combined Heat and Power (CHP) plant with an electricity of 30 % 174.4 kW can be used as electricity whereas 479.6 kW can be used as heat (thermal efficiency of 55%) [10]. Based on above calculation, it clearly showing that the amount of total gas volume is 109 m3 /day; its obtained from 2000 m3/d of wastewater flow which contents 6sludge which is highly a valuable renewable energy. With the introduction of new technologies for wastewater treatment, the energy requirements will change and alleviate the shortage of electricity and gas demand. Biogas systems are an environmentally friendly way of energy production and have a positive impact on climate change. As showing in below figure four, the amount of

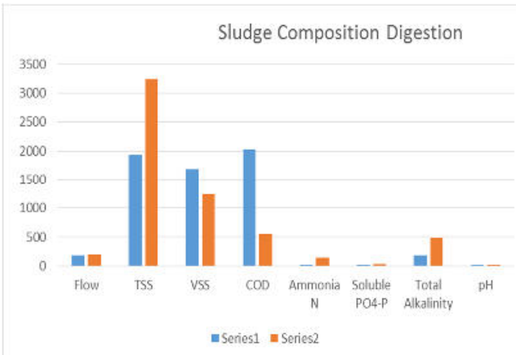

Figure 2. Sludge Composition and Characteristics

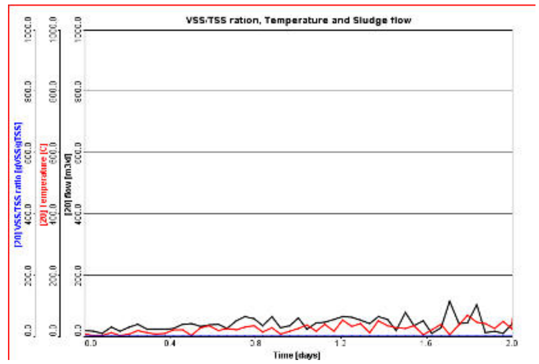

Figure 3. Sludge flow, proportion of VSS/TSS and temperature, based on time (days).

yielding gas has directly depend upon to the volatile suspended solids VSS destruction at entire process [8].

According to figure 4, the amount of total gas flow rate is 110 m3 / d and its captured through form 2000 m3/d of domestic wastewater plan which is counting valuable green energy that possibly could compensate 40 % energy demand of treatment plant.

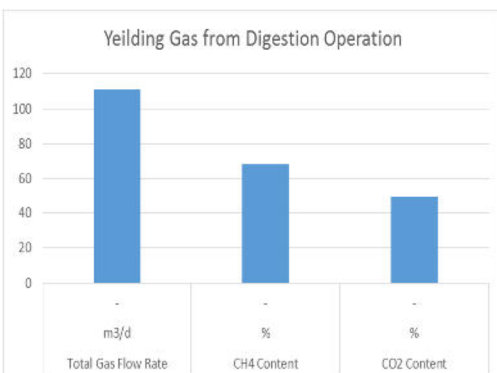

Figure 4. Yielding gas through digestion operation.

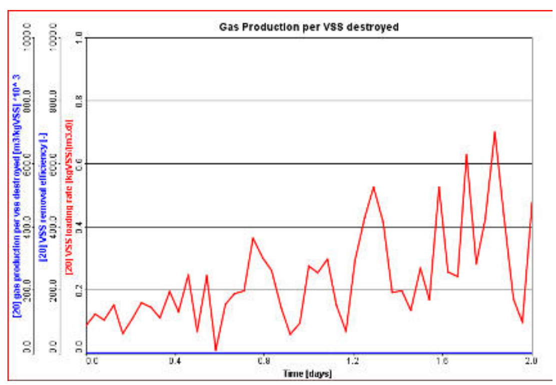

Figure 5. Showing Gas Production per VSS destroyed.

5.4. Methane production and heat requirements

One m3 biogas is produced during each day when the temperature of digestion is 5 degree or higher. Each cubic meter m3 of biogas contains the equivalent of 6 kWh of heating energy, when biogas is converted to electricity in a biogas powered electric generator, about 2 kWh of usable electricity can be obtained and remaining biogas is converted into heat which can then be used for heating applications [10]. The overall assessed value of biogas in from this treatment plant was 109 m3/day and electricity from derived biogas was 218 kWh, which is half of daily demand in wastewater wastewater's important resources are being utilized. These examples well demonstrate how overall energy requirements for treatment can be reduced through more energy-efficient practices in addition to capturing wastewater's energy potential, while simultaneously capturing its water and fertilizing nutrient resources. Today there is increased understanding of the importance of working toward renewable energy and recovery from waste to substitute as alternative of fossil fuels [11].

5.5. Suggestion for future work

Provision of renewable energy from biomass and biogas need broad institutional research and discussion topic with new ideas being explored all the time. It was an initiate step that have been learned in Japan and considering to conduct more research in order to explore renewable energy form different source of waste according to its availability by dissemination among local people government institutional and private sectors. At the future, specific research will conduct according to application of technologies, affordability, climatic and implementation into all Afghanistan region, where it is possible in every individual households to generate their own renewable energy respectively. Creating an energy awareness campaign among local people in urban and rural areas and encourage to learn more about renewable energy toward sustainability and environmental protection.

6. Conclusion

Energy capturing from waste and sludge is a new phenomenon in our country, despite, the successful implementation of the anaerobic treatment process depends upon understanding of various environmental factors which has directly affect the microorganisms that responsible for waste degradation. Therefore, to supply the in-house electricity and heat demand of the plant itself in a more economical and ecological way. The advantages of anaerobic treatment is include, but not limited:

1. By producing energy from biomass and biogas decrease the waste dispersal in cities and increase the suppling electricity and gasses.
2. Waste is source of valuable energy that could be easily used for multi purposes like (electricity, gas and heating) in order to reduce workload, mainly for women.
3. Renewable energy enabling families to do self-investment for their own generating energy.
4. Global environmental benefits within biogas and biomass technologies.
5. Economic benefits substitution of spending on an expensive fuels and fertilizer.
6. Improve indoor air quality less smoke and harmful particle emission of a biogas stove compared to wood or dung fuels.
7. Creating clean environment, alleviate the disease and improving live condition of people.

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