Environmental Research & Technology, Vol. 2 (2), pp. 93-97, 2019

Turkish JournalPark ACADEMIC

Environmental Research & Technology

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RESEARCH ARTICLE

Biogas production from sewage sludge as a distributed energy generation element: A nationwide case study for Turkey

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ABSTRACT

Sewage sludge is outcome of the wastewater treatment process. It contains hazardous biological and chemical compounds that need to be stabilized. Anaerobic digestion is among the stabilization methods of sewage sludge. Digestion process destroys organic fraction of sewage sludge and produces biogas (%65 Methane, %34 CO_2 and etc.). Biogas is burned in internal combustion engines to produce electricity. Digested residue can be used fertilizer. In this study, the total electricity production that can be obtained by anaerobic digestion of all wastewater treatment plants throughout the country is examined. Main objective of this study is preliminary evaluation of energy potential of biogas from sewage sludge anaerobic digestion. Since Wastewater Treatment Plants are distributed in the various regions of a city, above mentioned biogas plants should be considered as distributed generation equipment. Use of small scale energy production plants near the consumers is called distributed generation. Energy transmission losses and related infrastructure cost can be reduced or delayed by means of distributed generation. Within a smart grid approach, mentioned plants can support electricity grid. They can also serve as local emergency power plants. As a nationwide scenario WWTP are evaluated. Biogas energy capacity potential of 234 plants is calculated. Capacities less than 100 kWe are assumed to be non-feasible due to scale economy. It is evident that 91 plants can be installed with an average capacity of 660 kWe.

Keywords: Biogas, sewage sludge, distributed generation, waste to energy

1. INTRODUCTION

Global warming directs mankind to think energy and environment together. Most of the harmful emissions are produced by energy plants. There are two effective strategies to decrease emissions; increasing energy efficiency either in supply and demand side and exploitation of renewable energy sources.

Electricity supply system of a country should transmit clean, cheap, reliable energy. Energy should be available in every case. The planning of the energy mixture is dependent on countries' domestic resources. Primary energy sources are fossil fuels (coal, natural gas, fuel oil, biomass), renewables (hydroelectric, solar, wind, geothermal, biogas) and nuclear energy.

Centralized, conventional fossil fuel based power plants fulfills the major part of global energy production. Coal and natural gas are primary sources of electrical energy production. Coal causes high rate of emissions harmful to environment. Natural gas is not present in every country. However, natural gas being a trade material, it is also a political source. That affects energy security of countries.

Centralized energy production requires installation of high capacity transmission lines. As the technology and urbanization increases so the energy requirement. This causes risks of failure in the network. Development of new technologies also decreases the cost of small scale energy systems. Distributed generation (DG) approach encourages relatively lower capacity (<10MW) power plant installations in the energy demand area. By this aspect, transmission losses are prevented. When combined heat and power (CHP) systems are used for energy production, waste heat of process can also be used and hence increase system energy efficiency. DG

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Received 04 October 2018; Received in revised form 23 February 2019; Accepted 19 March 2019
Available Online 06 May 2019
Doi: https://doi.org/10.35208/ert.457466

can be used as emergency power supply in case of contingencies with the islanding capabilities [1].

In this study energy production potential of sewage sludge (SS) from waste water treatment plants (WWTP) is investigated. Biogas (from anaerobic digestion of SS) based electrical energy potentials are calculated. Since the most of the WWTP are located near the urban areas and distributed to different locations of a city, these plants can be considered as DG units. Evaluation results are discussed from nationwide DG aspect.

Capacity and properties of 234 existing and operational WWTP's are investigated. Information about WWTPs are compiled from public report of KAMAG Project named as "Management of Residential/Urban WWT Sludge Project", (Project number 108G167).

2. ENERGY PRODUCTION FROM SEWAGE SLUDGE

India's Solid fraction SS contains organic material. This organic material is combustible. SS calorific value is generally between 10-14 MJ kg^{-1} [2-4] and sometimes may reach 17 MJ kg^{-1} [5-7]. Combustion and anaerobic digestion are well investigated Waste to Energy (WtoE) approaches for Sewage Sludge (SS) [3, 6, 8-15, 16-18]. Direct combustion or co firing with coal or biomass is common energy production solution. Fertilizer recovery from ashes of SS [19, 22] is another option. Organic fraction of the sludge solids is digested by means of bacterial activity in special digesters resulting biogas production. Produced biogas can be converted to electrical energy in Gas Engines. Other emerging technologies to exploit energy from SS are gasification, pyrolysis and hydrothermal carbonization [17, 23, 24-31, 32]. In this study biogas option is selected as it is a mature technology. Digested stable material can be converted to fertilizer depending of composition. This approach supports recycle of biomass in natural environment.

3. RESEARCH METHODOLOGY

Design methodology for a single stage, high rate mesophilic anaerobic digester is given as summary [8] and as detailed [32] in the literature. Main measures of energy potential of a SS are wastewater feed (Q, m^3 day^{-1}) and biodegradable COD (kg m^{-3}). Within an anaerobic digestion process; pH, alkalinity, temperature, and retention times affect the rates of the different steps of the digestion [8]. Full design of a biogas plants require analysis of WWTP process and effluent values, area requirement etc. In this study rather than a case specific full design study a preliminary potential calculation performed. Biogas potential calculation methodology conducted according to [32]. Information of WWTP are collected from public report of KAMAG Project (108G167) Management of Residential/Urban WWT Sludge [33].

Biogas is a product of digestion of organic matter in the solid phase of the sludge. Biodegradable COD is the measure of organic matter in the sludge. Biodegradable COD loading to digester can be calculated using Equation (1). Total volatile solid production per day is calculated with Equation (2).

$$COD_b\ Load=COD_b*Q \quad (1)$$

In Equation (1) CODb is the ratio of biodegradable COD in sludge, (kg COD m^{-3} sludge). Q is the wastewater flow, m^3 day^{-1}.

$$P_x=Y*Q/(1+k_d*SRT) \quad (2)$$

In Equation (2), Y (=0,08) and kd (0,02< k_d <0,04 for mesophilic conditions) are the yield coefficient and endogenous coefficient respectively. Yield coefficient is the ratio of volatile solids production per COD_b (g VSS g^{-1} BOD). kd is constant and accepted as 0.03 [32]. SRT is sludge residence time (days) in the digester. In the mesophilic conditions, for SRT values above 12–13 day; changes in volatile solids destruction increase are rather small [8]. Hence the SRT is accepted as 13 days. Methane (CH_4) gas production per day is calculated according to Equation (3).

$$V_{CH4}=0.40*(COD_b\ Load*C)-1.42*P_x) \quad (3)$$

Biogas composition of AD of sewage sludge is %50-75 CH_4, %24-40 CO_2, %1-2 H_2O and relatively small amount of H_2S, N_2, H_2, O_2 also present [2]. As an averaging approach, Methane rate in biogas can be accepted as %65. Regarding to this value, total biogas production can be calculated using Equation (4).

$$V_{biogas}=VCH_4/0.65 \quad (4)$$

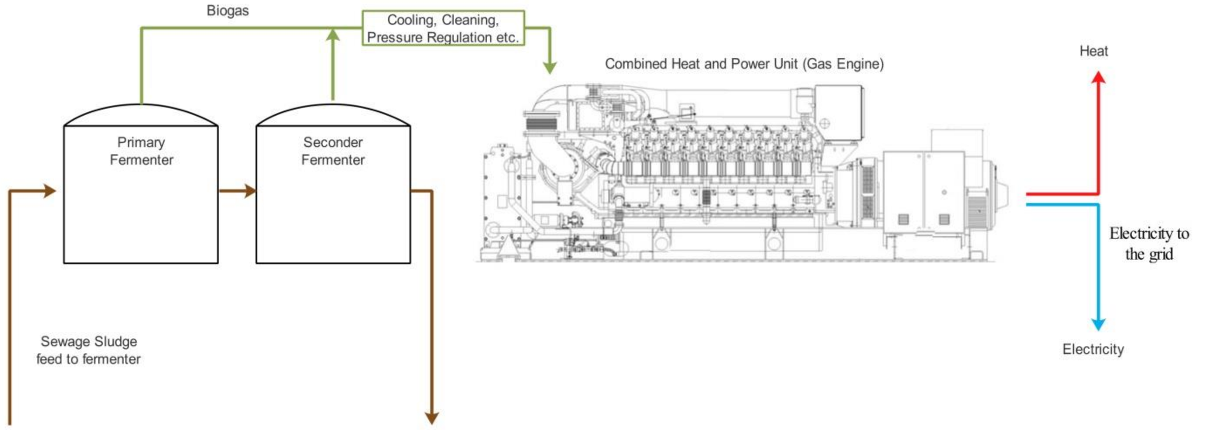

Fig 1. Energy conversion in a biogas plant

Table 1. Constant Parameters

Parameter	Value	Unit
Specific gravity of water	1.02	-
Solid content of sludge	5	%
SRT	13	days
Density of water	1000	kg m^{-3}
COD_b	0.3	kg m^{-3}
Waste conversion rate - C	50	%
Yield coefficienct - Y	0.08	-
Endogenous coefficient - k_d	0.03	-
Methane content of biogas	65	%
Methan conversion rate	40	%

Internal combustion engines, fuel cells, micro gas turbines are main devices for the electrical conversion of biogas. Internal combustion engine (gas engine) is selected as conversion device for the evaluation. Electrical conversion efficiency of a gas engine is %35. Biogas energy input can be calculated using methane gas calorific value, 35.8 MJ N^{-1} m^{-3}. Biogas Plant electrical capacity can be calculated according to Equation (5).

$$E_{biogas}=H_{CH4}*0.35 \quad (5)$$

4. RESULTS

Anaerobic digestion of organic waste produces two valuable products biogas and digestate that can be used as fertilizer [3]. Digestate is produced during anaerobic digestion and it is a valuable product in terms of nutrients [34]. In this study energy potential of 234 WWTP in case of an anaerobic digester biogas production plant installation calculated using Equation (1)-(5). On the theoretical basis energy content of organic matter present in municipal wastewater, is higher than the energy requirement of the WWT process [35]. However, in practice WTPs are not a negligible source of greenhouse gases (GHG). In this regard, the collection of biogas from anaerobic digestion of sludge and energy recovery is an option for the reduction of GHG emissions [3].

Total potential energy capacity is found to be 60 MWe electricity. Total proposed plant number is 93. Energy production units located on WWTPs can be considered as distributed generation elements. Distributed generation of electricity by anaerobic digestion means that urban districts could be self-supporting in terms of electricity, heat and cooling [36]. Total potential capacity is 0.06% of country's installed capacity. Despite that the value is rather small in numbers, by using electricity and heat together overall utilization efficiency could reach to 90% causing an important save of GHG emission [36]. Average potential capacity of proposed plants is 660 kWe.

Fig 2 shows capacity of every plant with descending order. Plant size distribution is stable. High capacity (above 1 MWe) plants (listed in Fig 4) are located in the crowded cities.

Fig 3. Shows regional distribution of power plants. Energy potential depends on WWTP processing capacity and population. Marmara is the most urbanized region thus the highest potential capacity is calculated. Even the plant counts are high in the Akdeniz, Ege and Karadeniz regions total potential capacity is relatively small. This can be conclusion the fact that Akdeniz and Ege are touristic regions so the settlements are small and Karadeniz region is a highland so the settlements are distributed and small.

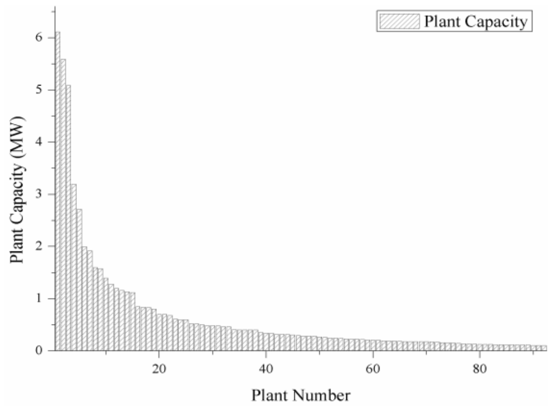

Fig 2. Distribution of capacity ranges of proposed biogas power plants

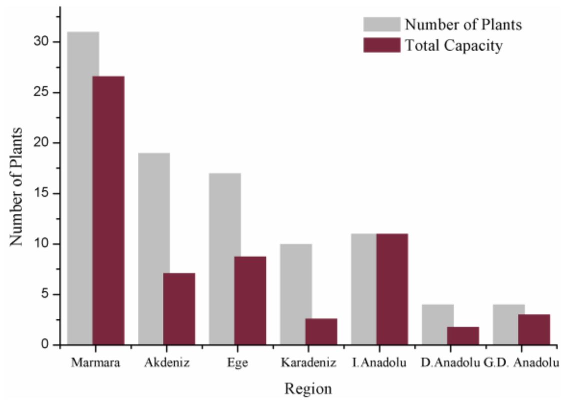

Fig 3. Regional distribution and capacity of plants

Capacity and names of 15 plants whose capacity are higher than 1 MWe are listed in Fig 4. 7 of 15 plants are located in the İstanbul -the most crowded city of Turkey. Other 8 plants are also located in the biggest cities of country. There is also options for increasing the energy potential of plants like co-digestion of SS with various organic waste. Co-digestion is an anaerobic digestion method with at least two different wastes that are mixed and digested together. Among the options for additional waste for co-digestion, landfill leachate and organic fraction of municipal solid waste are proved to increase biogas production rate [34].

Among the advantages of the DG is support of supply during the peak load conditions. SS based biogas plant energy production generally do not fluctuate. This is an important advantage over solar and wind systems. There are also constraints for the integration of distributed generation like price of electricity, power quality, infrastructure requirements, and technical performance [37].

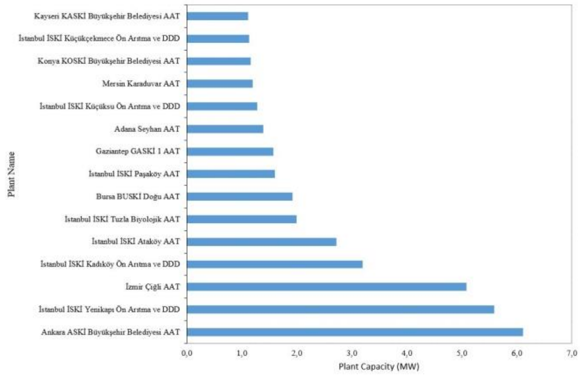

Fig 4. List of plants with a capacity of more than 1 MWe

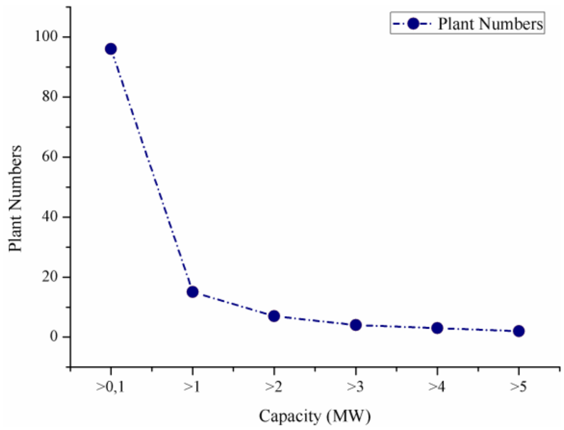

Fig 5. Capacity distribution of proposed plants

5. CONCLUSIONS

Sewage sludge is a valuable source rather than a waste. Exploitation of energy potential of this abundant resource can be accomplished by various methods including biogas production. In this study electricity production by using biogas plants is investigated for all of WWTPs of the country. 91 of the 234 plants are found to be feasible (electrical capacity >100 kWe) for biogas installation regarding potential electricity capacity. Regarding the wastewater flowrate %95 of total capacity can be used in electricity production. As an alternative option, power demand fluctuations in peak hours can be managed with built in biogas storage units.

For the non-feasible group of plants, installation of regionally centralized combustion plants can be analyzed. Collected sludge can be dried and combusted to produce electricity. Further studies should be conducted on two aspects: Feasibility analysis of proposed biogas plants with region specific SS properties values and economical aspects and preliminary design of common combustion plants for small scale plants sludge in every city.

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