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Comparison of methods for sustainable energy management with sewage sludge in Turkey based on SWOT-FAHP analysis

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ABSTRACT

The sewage sludge creates as a result of wastewater treatment and has high water content, contains pathogens, heavy metals, micro-pollutants, etc., and also include organics that have a high calorific value, nitrogen and phosphor; therefore, it is necessary to select sustainable methods in its treatment/disposal. As for sustainable sludge management, not only current technologies, but also several other criteria such as legal regulations and problem-solving need to be taken into account. This study summarized the current situation for the management of domestic sewage sludge in Turkey and compared the methods of anaerobic digestion, incineration, gasification, pyrolysis and supercritical water gasification (SCWG), which are used/can be used in Turkey, with one another on the basis of four different criteria. As a result of the SWOT-FAHP (fuzzy analytic hierarchy process) analysis performed, it was observed that supercritical water gasification, which is one of the five methods considered, and problem-solving criterion, which is one of the four criteria considered, had the highest weight values. According to the results obtained via comparison of criteria, it was determined that the availability of current technology had less importance than problem-solving criterion in the selection of an appropriate method. The reasons why the method of supercritical water gasification had a high weight value even though it had certain disadvantages can be listed as follows: it ensures treatment with a high yield, does not require pre-treatment, has a shorter reaction time and creates a higher amount of beneficial by-products as compared with harmful emissions. Furthermore, this study also touched upon the obstacles to overcome for the development of SCWG and brought recommendations.

Contents

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1. Introduction

Sewage sludge refers to odorous and semi-viscous waste that includes solids at the rate of 0.25–12% depending on the applied treatment processes [1]. The sludge that is generated at various steps in the treatment plant has specific characteristics such as solid concentration and biological degradability. Therefore, sludge characteristics vary as per the local conditions and treatment method. Table 1 illustrates the composition of domestic sewage sludge in various regions of Turkey. As can be seen from the table, characteristics of sewage sludge vary per region, treatment unit and season. The sewage sludge which is generated as a result of wastewater treatment contains recoverable organic carbon, nitrogen, phosphor and some inorganic compounds (silicates, aluminates, etc.). Additionally, the heavy metals in its composition (zinc, lead, copper, chromium, nickel, cadmium, mercury, etc.) and recalcitrant organic compounds (polychlorobiphenyls – PCB, dioxins, pesticides, etc.) ascribe dangerous characteristics to the sludge. Since sewage sludge has a high water content (> 90%), it has a higher volume. For that reason, the methods of disposal for sewage sludge are limited and they are difficult to manage the financial and environmental terms. However, its high organic matter content (> 40%) as well as the macro (nitrogen: 3%, phosphor: 2%, potassium: 50.5%) and micro (iron, zinc, nickel, copper, manganese, etc.) elements in its content make it a matter which can be used rather than being a waste matter [2]. Furthermore, the amount of sewage sludge is increasing day by day in parallel with rising population and increasing urbanization and industrialization. Approximately 50% of wastewater treatment cost is accounted for sludge treatment [3,4] and sludge treatment contributes to approximately 40% of greenhouse gas emissions released from wastewater treatment processes [4].

2. Management of domestic/municipal sludge treatment in Turkey

In our country, highly important steps performed by legal arrangements during the European Union (EU) accession process have been taken and priority areas on environment have been identified (Turkey's National Program for the Adoption of the European Union (EU) Acquis, 2003). Accordingly, the studies to be carried out in relation to sludge management are included in priority study areas. For that reason, current regulations have been put into place within the framework of Environment Law number 2872 and its subsidiary Water Pollution Control Regulation, Urban Wastewater Treatment Directive, Technical Procedure Communication for Wastewater Treatment Plants, Regulation on Landfill of Waste, Regulation on Soil Pollution Control and Point Source Contaminated Sites, Regulation on the use of Domestic and Urban Sewage Sludge in soil as well as Regulation on Waste Incineration and Waste Management Regulation.

According to data by the Turkish Statistical Institute [10], 460 wastewater plants serve 58% of the population of Turkey as determined in 2012. Taking the average sludge generation as 40–46 g of solid matter per capita per day [11] and taking into account the population that is served by treatment plants, it is calculated that approximately 1700–2600 t of domestic/municipal sewage sludge per day is generated by the current treatment plants.

The treatment and disposal methods for sewage sludge with high water content (< 90%) include anaerobic digestion, landfill, incineration and using for agricultural purposes, and some criteria (pre-treatment as drying, destruction of heavy metals and toxic contents, etc.) in the regulations for the use of this methods are required to be fulfilled. In Turkey, 29% of domestic sewage sludge are stabilized by implementing the anaerobic digestion method. As for the remaining part, 52% is stabilized by aerobic digestion, 16% by lime and 2% by composting method. Furthermore, 26% of the sludge that are generated are finally disposed of in solid waste landfill plants, one of the most economical and easiest method to implement, 6% by agricultural use, 5% in incineration plants or by use in cement production as additional fuel and the remaining 63% by the use of other methods. In Europe, 40% of sewage sludge generated is disposed of in landfill plants, 37% in agricultural use, 11% in incineration and 12% in different means [12]. In European Union countries, 18% of domestic sewage sludge is disposed of in landfill plants, 23% by thermal methods, 45% by use in soil, 7% by composting and the other 7% by other methods; on the other hand, in USA, 45% of domestic sewage sludge is disposed of in landfill and incineration plants, 21% in agricultural use, 12% in landscape use and 2% for soil remediation purposes.

The calorific value of domestic sewage sludge is 2500–3500 kcal/kg (10,460–14,644 kJ/kg) and changes depending on the treatment processes. The average calorific value of raw sludge is 6094 kcal/kg (25,497 kJ/kg), average calorific value of activated sludge is 5019 kcal/kg (20,999 kJ/kg) and the average calorific value of sludge stabilized by anaerobic digestion is 2629 kcal/kg (10,999 kJ/kg) [2].

In Turkey, anaerobic digestion is generally used in order to recover energy from domestic/municipal sewage sludge. However, it would not be sufficient to take into account only current technologies (high treatment yield, product recovery, emission generation, etc.) for sustainable sludge management. For this purpose, it is necessary to compare different methods with one another according to different criterion. Samolada and Zabaniotu [13] performed SWOT analysis for a sustainable municipal sewage sludge management in Greece, not only the available technologies, but also other parameters, such as policy regulations and socio-economical issues that should be taken in account. The study showed that pyrolysis seems to be the optimal thermochemical treatment option compared to incineration and gasification. Goksel [14] investigated the energy based approaches of four different processes (pyrolysis, incineration, gasification and landfilling) in the waste management with SWOT analysis. Also, SWOT analysis has been performed in the literature related to waste-oil management [15], the status quo of construction waste management in South China [16], the current status of renewable energy sources and systems in Jordan [17] and the development of renewable energy policies and roadmaps in Japan, South Korea and Taiwan [18].

The purpose of this study is to compare five methods that are used or can be used for energy recovery from domestic/municipal sewage sludge in Turkey by taking into account four different criteria using SWOT-FAHP (fuzzy analytical hierarchy process) analysis and to determine the optimal method. SWOT analysis makes it possible to determine the strengths and weaknesses of every method as well as opportunities and threats. Furthermore, the strengths and weaknesses as well as opportunities and threats can be taken into account by means of SWOT-FAHP and these weight values obtained aid in the selection of the most optimal one among the methods considered.

3. Energy recovery processes from sludge

In our day, sludge treatment approaches are 1) reducing mass and volume to ensure additional treatment, 2) elimination of pathogen microorganisms, elimination of undesirable odors and ensuring stability of volatile solid matters, 3) recovery of energy and useful compounds [4]. To realize energy or heat recovery from sewage sludge, biochemical (anaerobic digestion, gasification) and thermal (incineration, pyrolysis, supercritical water gasification (SCWG)) methods can be employed. In the anaerobic digestion and