A CASE STUDY ON SEWAGE SLUDGE INCINERATION PLANT: GASKI

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ABSTRACT

Annual sewage amount in Turkiye increased to 3.5 billion m^3[1]. About %4 of the sewage can be considered as sludge so 140 million tonnes of sewage sludge potential is present in Turkiye. Some municipals have waste water treatment plants where wastes are separated from water. Gaziantep municipal has also a waste water treatment plant (WWTP). Daily amount of sewage sludge is about 150 tonnes and the first incineration plant of Turkiye is founded in the city. A drier and a fluidized bed furnace is used in the plant. Overall capacity of incineration is about 180 tonnes/day. The manuscript describes basics of the plant and also production of electricity.

1. INTRODUCTION

The acceleration of population growth and urbanization process brought a considerable volume of sewage. The annual produced sludge has been and will continue to increase in the foreseeable future.

Disposal of sewage sludge is a challenging environmental issue emphasized by the continuously increasing volumes of sewage sludge generated by municipal WWTP. The environmental legislation is becoming more and more restrictive as regards landfilling of this biodegradable waste. The progressive decrease of the use of sludge in agriculture, which can only be considered under very well controlled conditions due to the presence of heavy metals and pathogens, further stimulates the search for alternative disposal pathways. In this context, thermochemical conversion of sludge is gaining broader consideration. Combustion and co-combustion are currently indicated as viable processes to dispose of sewage sludge [2].

Sewage sludge is a complex heterogeneous mixture of microorganisms, undigested organics such as paper, plant residues, oils, or fecal material, inorganic materials and moisture [3]. On the other hand, the expense for sludge treatment is costly, which has been estimated to take up 50–60% of the total operational costs in WWTPs [4].

2. ALTERNATIVES OF SLUDGE DISPOSAL

Municipal wastewater treatment results to the production of large quantities of sewage sludge, which requires proper and environmentally accepted management before final disposal. Tons of sewage sludge is leading to severe environmental problems, such as large quantities of malodorous gases, the numerous pathogenic or disease-causing micro-organisms and heavy metal pollution [5]. Sustainable sludge management is becoming a major issue for wastewater treatment plants due to increasing urban populations and tightening environmental regulations for conventional sludge disposal methods.

Global population growth with rapid industrialization and urbanization, the volume of recently produced sewage sludge has dramatically increased. In the European Union and in China, more than 10 and 20 million tons of sewage sludge are respectively produced annually [6].

Conventionally, the waste sludge is disposed via incineration, landfilling or ocean disposal as well as reused as soil conditioner in agriculture. With the recent banning of ocean disposal and new stringent European landfilling criteria, much more sludge is now reused both in agriculture and via a variety of thermal technologies [3]. An alternative to these options was sea disposal of sewage sludge but this has been banned in EU countries since 1999 following the implementation of the EU Urban Wastewater Treatment Directive (1991) [7].

In European Union, sludge management remains an open and challenging issue for the Member Implementation of UWWT Directive (CEC, 1991) by EU-12 countries is going to cause a significant increase of annual sewage sludge production in EU during the following years, exceeding 13 million tons dry solid up to 2020. States as the relative European legislation is fragmentary and quite old, while the published data concerning sludge treatment and disposal in different European countries are often incomplete and inhomogeneous. More stringent legislations comparing to European Directive 86/278/EC have been adopted for sludge disposal in soil by several European countries, setting lower limit values for heavy metals, pathogens and organic micropollutants. Regarding sludge final disposal, sludge reuse (including direct agricultural application and composting) seems to be the predominant choice for sludge management in EU-15 (53% of produced sludge), following by incineration (21% of produced sludge). On the other hand, the most common disposal method in EU-12 countries (new Member States that joined EU after 2004) is still landfilling. Due to the obligations set by Directive 91/271/EC, a temporary increase of sludge amounts that are disposed in landfills is expected during the following years in EU-12 countries. Beside the above, sludge reuse in land and sludge incineration seem to be the main practices further adopted in EU-27 (all Member States) up to 2020 [8].

More than 90% of population in Germany, Netherlands and UK is connected to urban wastewater treatment, whereas lower percentages are observed in Mediterranean and Eastern Europe countries. So far, there is not a clear view concerning sewage sludge handling (treatment and disposal practises) as well as relative legislation in EU area. Some relevant reports have been published by Eurostat, European Commission (EC) and European Environmental Agency (EEA); however, most of them refer mainly to agricultural utilization of sludge; whereas they are usually incomplete, inhomogeneous and contain sometimes contradictory data [8]. Sewage sludge disposal management practices in EU countries according to latest available data on Eurostat are given in figure 1. In the Netherlands, the Flemish region of Belgium and regions of Germany that have sandy soils, land-spreading has effectively been banned due to the adoption of prohibitively restrictive heavy metal limits for sewage sludge and sludge treated soils [7]. Incineration is the mostly preferred method for these countries and also for Slovenia and Switzerland.

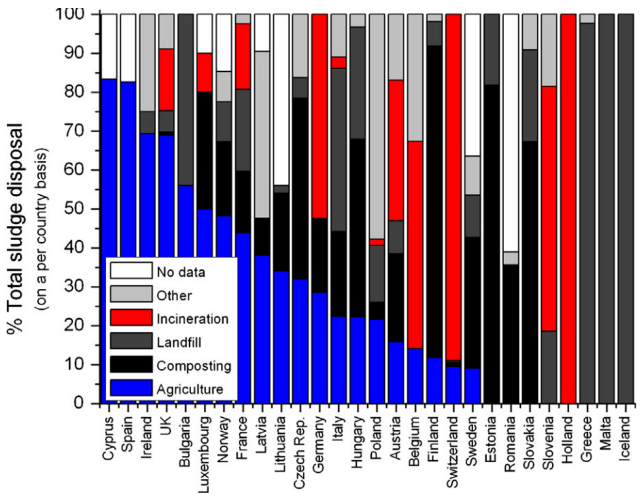

Figure 1 Sludge disposal methods for EU countries [7]

Wastewater treatment plants are striving to achieve a sustainable sludge management strategy due to the legal banning of conventional sludge disposal methods such as landfill. However, the rapid growth of urban populations has resulted in the production of increasing volumes of sewage sludge. Existing municipal wastewater facilities are reaching capacity, requiring expansion and upgrades to handle the additional load that is anticipated in future [9].

Utilization of waste sludge as a renewable resource for energy recovery is the appropriate solution of how to manage the continuously increasing waste sludge generation effectively in order to meet stringent environmental quality standards, and at the same time, how to sustain the supply of reliable and affordable energy for our future generations and ourselves [3].

The valuable characteristics of sludge, including high energy and nutrient content, with the stringent criteria of sludge disposal, driving the environmental engineers and scientist to change their standpoint to considering sludge as a viable resource of energy instead of a waste.

The two components in sludge that are technically and economically feasible to recycle are nutrients (primarily nitrogen and phosphorus) and energy (carbon) [3].

There are several options available for energy recovery from waste sludge. The significant routes are anaerobic digestion of sludge with biogas recovery, co-digestion, incineration and co-incineration with energy recovery, pyrolysis, gasification, supercritical (wet) oxidation, use in the production of construction materials, production of bio-fuels (hydrogen, syngas, bio-oil), electricity generation by using specific microbes, and beneficial recovery of heavy metals, nutrient (nitrogen and phosphorus), protein and enzymes.

Anaerobic digestion is the most popular sludge stabilization technology currently in the market. The process transforms sludge organic solids to biogas, which is a mixture of CH4, CO2, and traces of other gases, in an anaerobic environment. Anaerobic and aerobic digestion applying in 24 and 20 countries, respectively. Mechanical sludge dewatering is preferred comparing to the use of drying beds, while thermal drying is mainly applied in EU-15 countries (old Member States) and especially in Germany, Italy, France and UK [8].

Outside of the EU, there is a long history of sewage sludge incineration in the USA and Japan. Densely populated regions such as those in Japan have the double problem of high quantities of sludge production and low land availability. The largest sewage sludge incineration plant in the world is currently under construction in Hong Kong and is expected to produce around 240,000 tonnes of ash per year from 2013 onwards [7].

Countries focus on methods that will advance the use of renewable energy, as well as achieve cleaner and more efficient energy consumption [6]. Incineration may serve to aim of obtaining clean energy using the waste.

3. INCINERATION

Incineration is one of the major methods for the resource recovery during disposal of sewage sludge which has been widely applied in many developed countries and some newly industrialized areas in recent years. It is an effective way of sewage sludge disposal [5]. Incineration can achieve stabilization, volume reduction and resource recovery of sludge. Incineration is enforced in most EU-15 countries.

The main purpose of sludge incineration is the complete oxidation of the organic compounds at high temperature. In this process, the bio-solids are burned in a combustion chamber supplied with excess air (oxygen) to form mainly carbon dioxide and water, leaving only inert material (ash). This ash has to be disposed of or can be used as a source for the production of building materials. Presently, sludge incineration methods are progressively determined on the energy recovery from the sludge in the form of heat or electricity [3].

Incineration is increased from 11% to 21 % from 1992 to 2005 in EU-15 countries. Landfilling presents a significant and continuing decrease between 1992 and 2005, from 33% to 15%. On the other hand, sludge incineration has been almost doubled (from 11% to 21%) [8].

Netherlands presents the greater preference in all types of incineration, followed by Belgium (53%) and Germany (51%). In Flemish region of Belgium, incineration is applied in 88% of produced sludge [8].

Sewage sludge combustion is different from normal fuel combustion due to the high quantity of water present. Sewage sludge typically has to be at least 28–33 wt.% solids to burn auto-thermically, with no requirement for external fuel to maintain the incineration process. Some researchers [7] have examined the combustion of sewage sludge with significantly higher solids content, with the aim of minimizing supplementary fuel requirements.

The process cannot be considered as a complete disposal option because significant quantities of inorganic incinerated sewage sludge ash remain. The general characteristics of ash have been reported in the literature [7] and this shows that the major elements in ash are Si, Al, Ca, Fe and P. Crystalline forms of these elements are invariably quartz (SiO_2), whitlockite ($Ca_3(PO_4)_2$) and hematite (Fe_2O_3). Aluminum is typically present in feldspar and XRD amorphous glassy phases. Amorphous glassy phase content can vary considerably between ash samples. This is an important characteristic when considering ash as a potential pozzolanic additive in blended cements.

There are many alternatives for use of ash in different applications. These include the use of ash as a substitute for clay in sintered bricks, tiles and pavers, and as a raw material for the manufacture of lightweight aggregate. Incineration ash has also been used to form high density glass–ceramics. Significant research has investigated the potential use of ash in blended cements for use in mortars and concrete, and as a raw material for the production of portland cement [7].

Ashes produced by thermal treatments of sewage sludge exhibit common properties with cement. For example, major elements present in sewage sludge ash are the same of major elements of cement. Hydraulic properties of ash are quite the same of cement ones. They may therefore be used to substitute part of cement in concrete or other cementitious materials, provided that technical prescriptions are satisfied and that environmental risks are not significantly increased [10].

Thermal processes such as incineration and gasification offer good solutions for the treatment of sewage sludge from wastewater treatment plants in large cities (Sabbas et al., 2003). Fluidized bed technologies are well adapted and developed worldwide for sewage sludge incineration [10]. Thermo-chemical conversion of sewage sludge in fluidized beds is an attractive path to reduce the amount of waste.

Technologies based on fluidized bed combustion are attractive, due to their inherent operational flexibility, high efficiency, low pollutant emissions, ability to effectively accomplish destruction of micro-pollutants and pathogens [2].

4. GASKI

The first incineration plant of Turkiye is designed for disposal of 180 m^3/day sewage sludge with 27% solid content (SC) that is produced by WWTP. The incineration plant is located on area of WWTP of GASKİ in Gaziantep. Design of the plant is done compatible with regulation about solid waste control, soil pollution control and also with environmental regulations and conformity to EU norms. Main aim of the project is incineration of the sewage sludge and use of it as a thermal source.

The contract for construction of the incineration plant is signed between GASKİ and Polyspin in 2010. The contract contains construction of the plant in one year and operation by the contactor for two years. The construction of the plant is completed by the end of 2011 and it is operated and continuously optimized by the contactor.

The incineration plant is based on a fluidized bed incinerator technology with a pre-drier. The units of the plant are: Sludge feeding tank, conveyor belts, heating unit for partial drying of sludge, fluidized bed furnace, fuel oil burner, combustion air blower, sand feeding system for fluidized bed, heat exchangers, solid waste cyclone, fine dust separating cyclone, exhaust gas filter, heat and noise insulations, plumbing connections, electric and automation system. A view of the plant with some units are given in figure 2. Also the drier is given in figure 3.

Figure 2 Furnace, economizer, cyclone and dust filter of incineration plant.

Figure 3 Drier of incineration plant

4.1 Design

Design requirement is incineration of sludge at a rate of 180 m^3/day which is 27% SC. According to this requirement drier and fluidized bed furnace dimensions are determined. Dimensions of all other components are designed in accordance. The whole system is designed to be fully automatic. Automation and control of parameters can be observed and set from operator panel placed in control office. Some other design properties can be listed as:

- Design is proper for evacuation of drier and furnace in the case emergency stop or electricity interruption,
- Drier and fluidized bed furnace are integrated and designed for no operator intervention,
- All system is designed for minimum energy consumption. (minimum fuel consumption at start up and minimum electricity consumption during operation),

Figure 4 Flowchart of incineration system

- Instant exhaust gas analysis and emergency warnings if the limits are exceeded,
- Carbon content of ash is less than 3%,
- Maximum exhaust gas temperature is less than 930^{o}C in the fluidized bed furnace,
- Air entrance temperature is set to a temperature to provide combustion without addition of extra fuel,
- Sand feeding is designed to feed sand for furnace bed,
- Heat exchangers are designed to obtain energy requirement of drier,
- Direr is designed to prevent any fire or explosion,
- All air circulation systems are designed for low speed air velocity,
- Temperature and pressure is measured and recorded at critical points.

Flowchart of the designed incineration system is given in figure 4. The properties of main units are given blow:

Sludge feeding tank: Incineration plant is designed to use sludge of some close waste water treatment plants. Hence the tank is designed for easy unloading of the trucks.

Drier: Sludge is fed from tank to drier by a conveyor belt. The drier is designed for drying and translating the sludge. Walls of the drier are heated with hot oil. The drier is isolated to prevent heat loss from outer surfaces. Rotating velocity, temperature value, sludge feeding rate are all automatically controlled. Partially dried sludge is fed to furnace at the exit of the drier (Figure 3).

Condenser: Evaporated water and other gases are carried to condenser. The water obtained from condenser is discharged to waste water treatment pool.

Fluidized Bed Furnace: Partially dried sludge is fed into fluidized bed furnace. Sludge is fed into furnace from several points while hot and pressurized air is given from furnace bed using special nozzles. Air temperature and velocity are controlled from control panel. The inlet air temperature is set in the air heating system to the desired value.

Combustion chamber is a cylindrical tube; inside is covered with brick while outside is isolated. During start-up of the furnace fuel-oil used to heat the furnace up to desired temperature. After heating of the furnace, sludge is fed into furnace. The sand bed temperature is typically 750^{o}C and the overhead freeboard zone at 800–900^{o}C. During combustion some amount of bed sand is carried by exhaust gases. Sand is fed into furnace 5% at a period of 300 hours.

The sand bed acts as a ‘‘thermal fly wheel’’ and helps stabilize temperature fluctuations in the incinerator. Particle residence times in the combustion chamber are typically only 1–2 s and during this time water is evaporated, volatile metals vaporize and organic compounds are combusted completely to gases. The remaining inorganic material is carried out of the chamber as fine particulates with the exhaust gases. Figure 5 is showing the furnace bed during operation.

Figure 5 Fluidized Bed of furnace

Heat exchangers: Oil is heated in the furnace using exchangers. Some of the heat is used in the drier while remaining is carried to cooling fans.

Cyclone: Exhaust gases from furnace enter to cyclone to separate sand and large ash particles. The separated particles are sent to ash silos.

Dust filter: The exhaust gases coming from cyclone are filtered. The filtration system is designed for high performance. Some harmful gases are also filtrated at his unit.

Chimney: Exhaust gases cleaned from particles are entering to chimney where some measurements are performed to check burning performance. Condensation is prevented and exhaust content is measured and recorded instantly. Relased exhaust from the chimney is mainly water vapor with minimal hazardous content. A photograph of the chimney during operation is given in figure 6. Result of exhaust analysis is given in table 1. The values of exhausted hazardous gases are very low compared to limiting values.

Figure 6 Chimney of Incineration plant

Table 1 Exhaust Analysis

Parameter (mg/Nm^3)	Mean Recorded Value	Limiting Value
Chlorine	2.63	60
Fluorine	< 0.04	4
CO	5.00	200
NO	4.78	200
SO_2	21.17	200

Ash silo: Ash collected from cyclone and filters are carried to ash silos where the ash is loaded to trucks periodically.

4.2. Working principle

The sewage sludge from waste water treatment plant of GASKİ is fed to feeding tank at a rate of 180 m^3/day with 27% SC. Sludge is fed into drier by a conveyor. The drier is heated by hot oil where the heat source is fluidized bed furnace. Vapor obtained from drier is condensed and transferred to entrance of waste water treatment plant. Remaining gases are fed into furnace to prevent offensive odor.

Partially dried sludge is pumped to furnace using positive displacement pumps. The sludge is incinerated here at about 850^{o}C. The combustion air is separated in two main groups: primary air and secondary air. The amount of primary air needed to be adjusted in such a way that there is sufficient air on the grate, and it is 90 wt.% of the total combustion air. Secondary air is crucial for secondary and complete combustion which is sprayed at the neck of the furnace through the secondary air nozzles. The exhaust gases containing particles vapor and other gases are transferred to cyclone where big particles in the exhaust is separated here. Comparatively big particles separated in cyclone are transferred to ash silos. After cleaning of exhaust gases via filters, gases are get out from chimney at about 120^{o}C. Ash from filters is also transferred to ash silos. Emission values are instantly recorded and checked for dust, NOx, SOx and CO.

The incineration system is completely automated where temperatures and pressures for critical points can be observed from operator room given in figure 7. Automation system is designed for instantly observing the operational parameters from screens given in figures 8 and 9.

Figure 7 Incineration plant operator room

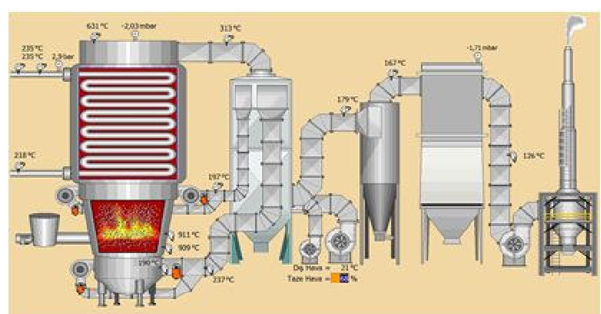

Figure 8 Observation screen for incineration

According to observed values, operator can instantly change the operational parameters from the operator's panel. The system is working with a closed loop control system where operator sets the target value from the operator panel. Target value and instantly changing operating value is screened together at operator's panel (figure 10).

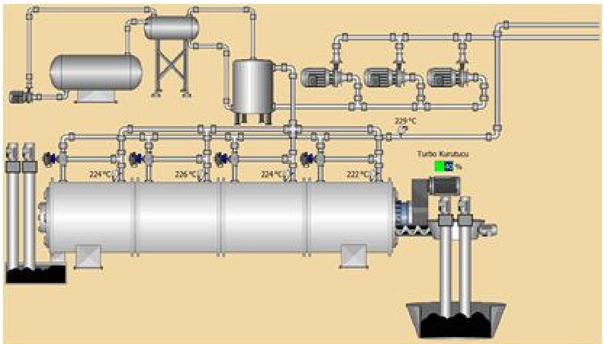

Figure 9 Observation screen for drier

Figure 10 Operator panel for entering operation values

4.3. Potential of Electricity

Thermal energy released during combustion is exchanged to oil and some of the energy is transferred to drier. Remaining energy is transferred to cooling fans. Energy is released to atmosphere from the cooling fans. Electricity energy potential of heat released from the fans is reported by the University to be about 2 MW. The energy potential is calculated measuring the flow rate of the hot oil from the cooling fans and inlet/outlet temperature difference of the oil at the fans. Efficiency of the turbine is also considered in calculations. It is planned to install a generator instead of the fans to produce electricity from the produced heat.

Power consumption of the incineration is about 0.25 MW where reported electric power potential is about 2 MW hence 1.75 MW of net electricity production will be possible from sludge incineration.

5. CONCLUSION

Management of sewage sludge is becoming a serious concern with increasing numbers of WWTP in Turkiye. Due to socio-economic and environmental regulation factors, it is a challenging task for the municipals.

Conventional sludge disposal methods such as disposal in landfills, disposal in seas or rivers and land application are already facing increasing pressure and protest from environmental authorities and from the public domain. Thus selection of an efficient and sustainable way for sludge management is a task for wastewater treatment authorities. On the other hand, increases in fuel prices, rapidly depleting non-renewable resources due to rising demand, public awareness as well as climate change issues drives the interest to utilize the waste sludge as a valuable resource of renewable energy recovery.

Considering these facts incineration is an effective way of sludge disposal due to its electricity production potential. The first incineration plant of Turkiye implies the economic potential of sludge and the plant is a good example for other municipals.

The feasibility of using ashes from sewage sludge incineration as a substitute to cement and/or sand in cementitious construction materials is another encouraging aspect of the incineration.

An incineration plant is a conversion point of annoying waste to energy and raw material for a municipal.

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