Design of Electron Beam Sludge Hygienization Plant

Y. Kim[1], B. Han[1], J. K. Kim[1], N. Ben Yaacov[2], K. Y. Jeong[3]

[1] EB TECH Co., Ltd., Daejeon, Korea
[2] Bar Idan Ltd., Shimshit, Israel
[3] Kongju National University, Korea

Email contact of main author: bshan@eb-tech.com

Abstract. The laboratory scale studies had been carried out regarding the possibility of electron beam application for sludge hygienization. Experimental system with nozzle type sludge feeder and stainless steel belt conveyor was constructed for irradiation under continuous feeding conditions of sludge cakes with electron beam of dose rate of 40kGy/s. Survival curves of microbial population for total coli-forms, fecal coli-forms, E. coli and Salmonellae sp. in dewatered anaerobic digested sludge cake deceased as a function of radiation absorbed doses. Based on laboratory data, an industrial scale plant with the capacity to treat 7,000 m^3 of dewatered sludge per month (18% solid contents) with 10 kGy has been planned. This plant will be equipped with an electron accelerator (2.5MeV, 100kW) and handling facilities, and is expected to be more economical than other sludge disposal processes, such as incineration, lime stabilization, etc. The utilization of electron beam on sludge will necessitate the development of technologies that can treat the sludge in a reliable, efficient and cost effective manner.

1. Introduction

It has been shown that a dose of 2–3 kGy destroys more than 99.9% of the bacteria present in sewage sludge and leads to the almost complete removal of helminth eggs and to the inactivation of the agents that cause disease in animals [Sabharwal et al., 2004]. Doses of this magnitude are employed for the radiation treatment of sewage sludges at an industrial plant in Geiselbullach, Germany [Lessel and Suess, 1984], and slightly higher doses (4 kGy) are used at a pilot plant near Boston, USA [Trump et al., 1984]. Higher doses (up to 10 kGy) are required to inactivate more radiation resistant organisms. Doses of 10 kGy were used at a sewage treatment plant in Albuquerque, USA [Sivinski and Ahlstrom, 1984], and at an installation in Ukraine [Vysotskaya, 1983]. In the 1980s, pilot plants based on an electron accelerator, were brought into service near Miami, USA [Cooper et al., 1998], and in Takasaki, Japan [Hashimoto et al., 1988]. At the electron beam sewage sludge treatment plant operated in Takasaki, dewatered sludge is spread through a flat, wide nozzle onto a stainless steel conveyor belt. After irradiation, the sludge is mixed with a bulking agent in order to make the product aerobic and is then moved to a conveyor belt where it is composted under conditions of controlled aeration and frequent mixing. More large scale plant using a gamma source is in operation in Vadodara, India [Sabharwal et al., 2004]. About 3 kGy of absorbed dose removes 99.99% of the pathogenic bacteria from liquid sewage sludge consistently, reliably and in a simple fashion.

2. Materials and Methods

A laboratory scale studies has been carried out regarding the possibility of electron beam application for sludge hygienization. In the experiments, electron accelerator of 2.5 MeV (variable from 1.0MeV), 100kW with the maximum dose rate of 40kGy/s was used. To carry out the experiments, the experimental system with nozzle type sludge feeder and stainless steel belt conveyor was constructed for irradiation under continuous feeding conditions of sludge cakes as shown in Figure 1 and Figure 2. The width and depth of sludge injection nozzle was designed to 300 mm and 7mm respectively, which was fit to the penetration range of 2.5 MeV electrons in sludge. The rate of sludge moving at the exit of the nozzle was controlled in 10-40 m/min, which treat up to 500kg of sludge cake per hour. The anaerobic digested sludge cake from the municipal wastewater treatment plant of Daejeon city was transferred to irradiation conveyor with mono pump from sludge hopper through injection nozzle and spread to desired thickness through thin flat nozzle. After irradiation, the treated sludge was collected into the storage container.

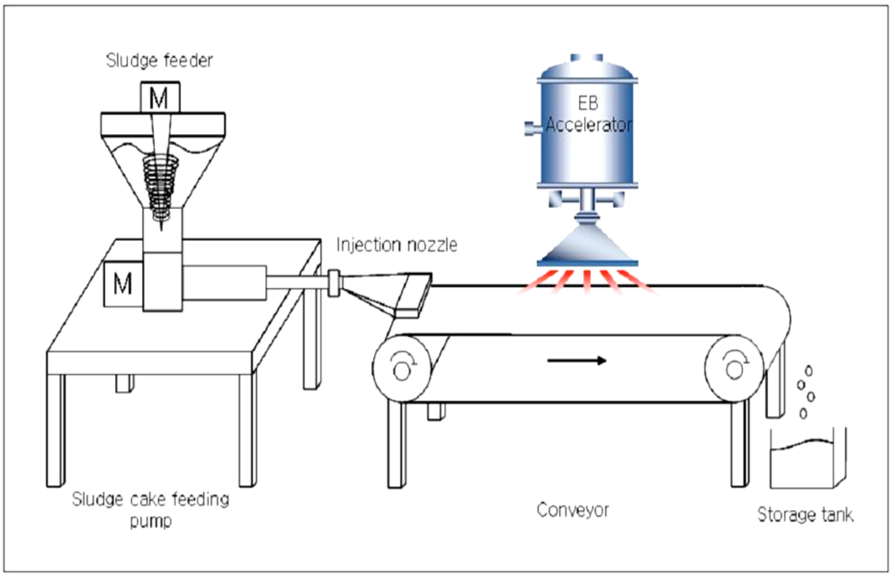

FIG. 1. Experimental apparatus for sludge hygienization

FIG. 2. Injection of sludge on the conveyor through nozzle

The sludge can be used as a soil conditioner and as an additive to animal fodder. However, it contains bacteria, viruses and parasites (and possibly toxic compounds) and should be disinfected prior to any such use. Guidelines by the U.S. Environmental Protection Agency (EPA) recommend that, in sewage sludge to be applied in agricultural practice, the number of E. coli bacteria (used as an indicator of the presence of pathogens) not exceed 1000 per gram of dry sludge [US EPA, 1993].

3. Result and Discussion

The radiation dose required to inactivate the pathogenic bacteria is generally defined in terms of the D_{10} value, which is the radiation dose required to reduce (through inactivation or cell death) the microbial concentration by a factor of ten or by one log cycle. In fact, this principle was the basis for producing radiation sterilized, single use medical products and is now well established in industry worldwide [Pikaev and Woods, 1994]. Based on the same principle, the pathogens present in sewage sludge can also be effectively removed by exposure to high energy radiation.

Survival counts of microbial population as a function of radiation absorbed doses for total coli-forms, fecal coliforms, E. coli and Salmonellae sp. in dewatered anaerobic digested sludge cake are shown in Figure 3, where coliforms are measured in MPN/g as dry solids (count in log scale), and Salmonella are measured in MPN/4g as dry solids (not in log scale). As showed in the figure, a dose of 3 kGy destroys more than 99.9% of the bacteria present in sewage sludge and leads to the almost complete removal of coli-forms and to the inactivation of the agents that cause disease in animals, and the D_{10} value would be less than 1kGy. At 3 kGy, for example 3-7 mm of thickness of sludge, the total counts for coliforms is reduced by 3 to 4 orders of magnitude and the fecal coliforms, E-coli, and salmonellae are reduced to below Class A levels. At 10kGy, the surviving fraction of microorganisms in sludge cake showed substantial elimination in the risk of pathogenic infection.

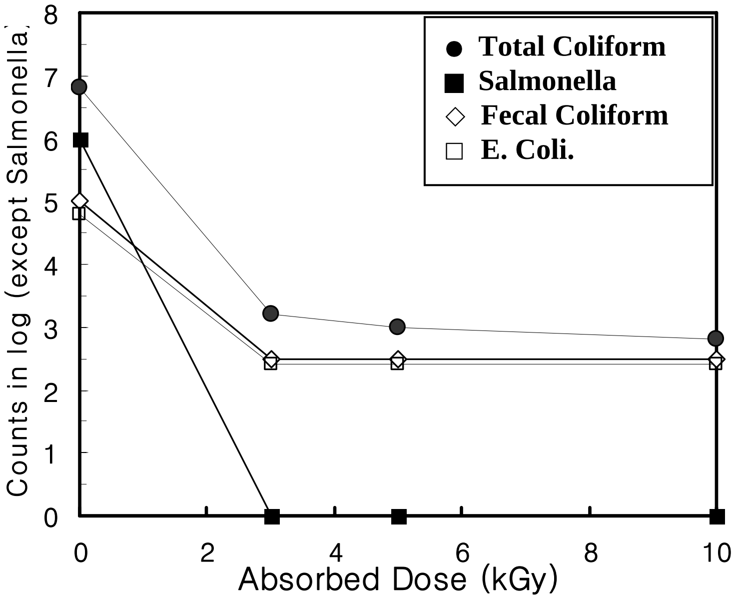

FIG. 3. Survival counts of microbial population at 1.0 MeV, 3mm thickness

4. Design of sludge hygienization plant

4.1. Design Parameters

According to the data obtained in pilot scale experiments, the industrial scale plant for treating 7,000 m^3 of dewatered sludge per month was designed with the optimum absorbed dose of 10 kGy. The plant will be located in Bet Shemesh wastewater treatment plant in Israel with 2.5 MeV, 100kW accelerator. The dewatered sludges (18%-20% solids) are stored in the intermediate container and pumped to the stainless steel belt conveyor under the electron beam through the nozzles. The layout and irradiation area of industrial plant is shown in Figure 5 and basic design parameters are as follows;

- Amount of sludge: 7,000 m^3 per month (22 m^3/h at working 16h/day in 5day/week)
- Absorbed Dose: 10kGy (according to the U.S. EPA Guide line)
- Electron Energy: 2.5 MeV
- Size of nozzle: 1,800mm width and 7mm thickness
- Speed of conveyor: 30m/min

With 16hours operation in a day with 20 days per month, to treat the 7,000m3 of sludge, 100 kW power of electron beam is required. When operated through month (24 hours at 30days), this plant can treat up to 15,000m^3 per month.

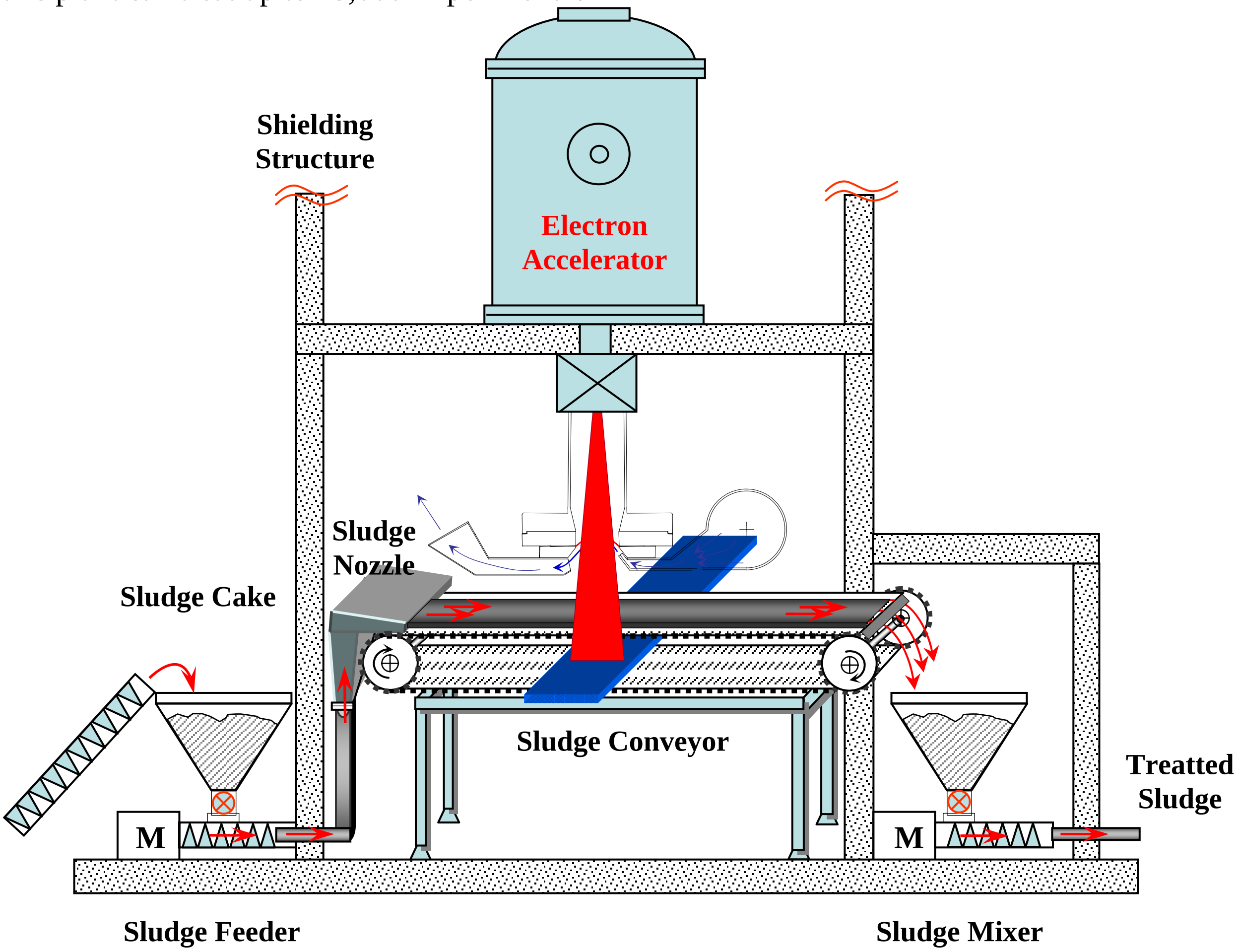

FIG. 4. Schematic diagram of conveyor and sludge feeder

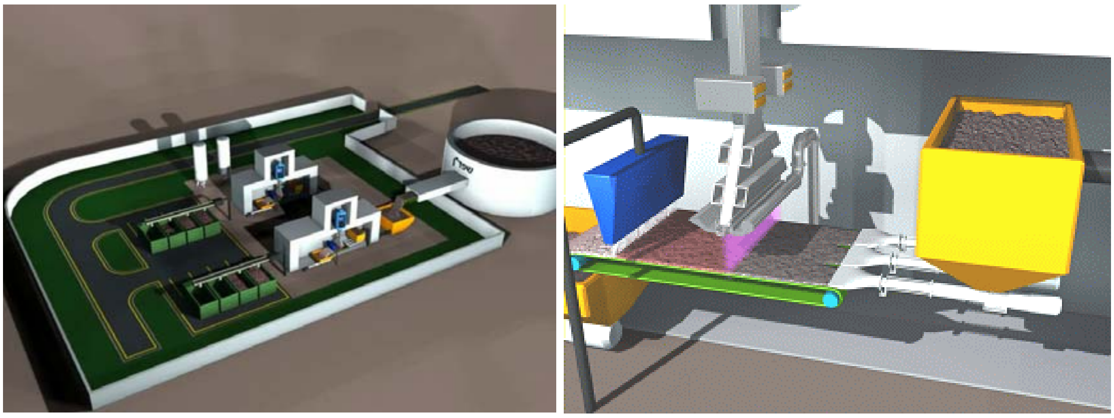

FIG. 5. Layout and irradiation area of industrial plant

4.2. Economics of sewage sludge treatment with e-beam

Based on the data of designed industrial plant, the cost assessment for sludge treatment plant has accomplished. Cost for accelerator, civil works, sludge handling equipments, and others are estimated as USD 1.98M. It also includes the cost for tax, insurance and other document works, not includes the cost for land, research, and Government approval. The capital cost for plant construction is explained in Table 1. Total construction requires 12 months including 4 months of civil work and 2 months of trial operation.

TABLE 1. CAPITAL REQUIRED FOR 7,000m^3 OF SLUDGE CAKES PER MONTH

Items	Cost in k$	Remarks
Electron accelerator(2.5MeV,100kW,1800mm window)	960	Cost for Land, R&D, Approval from Authorities are not included
Shielded Room (concrete structure) Sludge handling system (conveyor, feeder etc.) Transportation and Installation Auxiliary equipment (storage tanks etc. Others – documentation, tax, insurance etc.	1,020	
Total Capital Requirement	1,980	

To estimate the operation cost, it is assumed that the plant would operated 16hours in a day with 20 days working per month, and the electricity consumption of accelerator and other equipment is estimated as 150kW (70% efficiency). Based on the operation hours, the total electricity costs USD 60,000 per year when the cost of electricity (kWh) was assumed to be USD 0.05. The labor cost of operator is calculated on 2-shift work and is approximately USD 60,000 per year. Therefore, the actual operation cost for treating 70,000 m^3 per month comes up to USD 150,000 per year, and with including the interest (6%) and depreciation (20 years) of investment, it comes to USD 367,800 per year which is shown in Table 2. Therefore, the operation cost for cubic meter of sludge would be around USD 4.4, and if this plant treat up its maximum capacity (15,000 m3 per month), it may drop to USD 2.2.

TABLE 2. ANNUAL OPERATION COST OF INDUSTRIAL SLUDGE PLANT

Items		Cost in k$/year	Remarks
Fixed Cost	Interest	118.8	6%
	Depreciation	99	20yrs
Variable Cost	Electricity ((0.05$/kWh)	60	150kW
	Labor	60	2 shift
	Maintenance, etc.	30	1.5% of Capital cost
Total Operation Cost		367.8	
Operation cost (at 7,000m^3/month) is about USD 4.4 per m^3 of sludge cake			

5. Conclusion

Electron beam irradiation on the sewage sludge showed good removal of microorganisms in continuous irradiation system with conveyor and nozzle type feeder. At 3 kGy most all the microorganisms are disinfected in an order of 3 to 4, and at 10kGy the surviving fraction of microorganisms in sludge cake showed substantial elimination in the risk of pathogenic infection. An industrial sludge treatment plant with the capacity to treat 7,000 m^3 of dewatered sludge per month (18% solid contents) at 10 kGy has been designed with an electron accelerator (2.5MeV, 100kW) and handling facilities. The operation cost for cubic meter of sludge would be around USD 4.4, and it can be reduced to USD 2.2.

Acknowledgements

The authors would like to thank for the support of the Korea-Israel Industrial Research and Development Foundation, Korea Science and Engineering Foundation ; Ministry of Education, Science and Technology (MEST).

References

[1] Sabharwal, S., Shah, M.R., Kumar, N., Patel, J.B., Technical and economical aspects of radiation hygienization of municipal sewage sludge using gamma irradiator, Consultants Meeting on Radiation Processing of Gaseous and Liquid Effluents, IAEA, 2004.

[2] Lessel, T., Suess, A., 1984, Ten years experience in operation of sewage treatment plant using gamma irradiation, Radiat. Phys. Chem. 24, 3–16.

[3] Trump, J.G., Merrill, E.W., Wright, K.A., 1984, Disinfection of sewage waste water and sludge by electron treatment, Radiat. Phys. Chem. 24, 55-66.

[4] Sivinski, J.S., Ahlstrom, S., 1984, Summary of cesium-137 sludge irradiation activities in the United States, Radiat. Phys. Chem. 24, 19-27.

[5] Vysotskaya, N.A., 1983, "Radiation Treatment of Sewage Sludge" in Role of Chemistry in Environmental Conservation, Naukova Dumka, Kiev, p. 205 (in Russian).

[6] Cooper, W.J., Curry, R.D., O'Shea, K.E., 1998, Environmental Applications of Ionizing Radiation, John Wiley and Sons, Inc., New York.

[7] Hashimoto, S., Nishimura, K., Machi, S., 1988, Economic feasibility of irradiation composting plant for sewage sludge, Radiat. Phys. Chem. 31, 109-114.

[8] United States Environmental Protection Agency, 1993, Standards for the Use and Disposal of Sewage Sludge, US EPA, Washington DC.

[9] American Public Health Association, 2005, "Standard Methods for the Examination of Water and Wastewater", 21th Edition, 2005, Part 9921 B,D,E,F & 9260 D

[10] Pikaev, A.K., Woods, R.J., 1994, Applied Radiation Chemistry: Radiation Processing, John Wiley and Sons Inc., New York.