Design of Electron Beam Sludge Hygienization Plant

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What is Sludge ?

Sludge is the waste generated from domestic premises and consists mainly of human waste. It typically contains **99.9% water and about 0.1% solid**.

Why the sludge is important ?

Solution for the organic matter in agriculture

Current Problems

- Degradation of top soil layer resulting in decline in soil productivity.
- Excessive use of inorganic chemical fertilizers
- Overuse of water for cultivation

Solution

- Sludge is a rich source of many macro (N,P,K) and micro nutrients essential for soil, and also a rich source of organic Carbon for soil conditioning – organic farming.

Sewage sludge disposal and Recycling

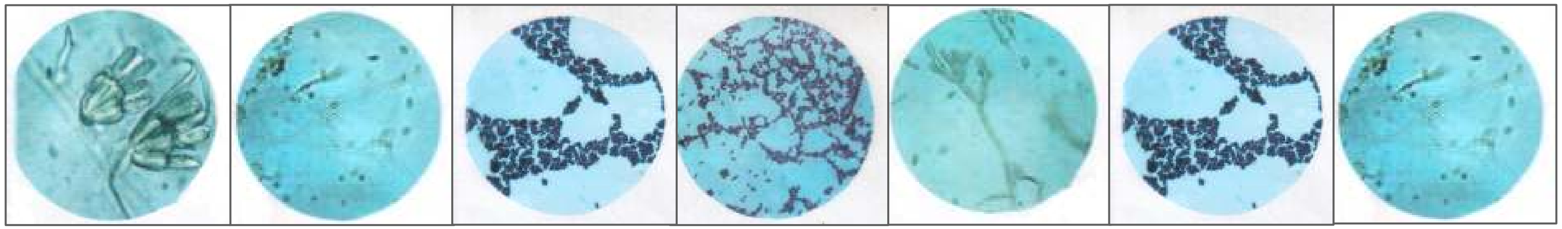
(unit : 1000ton/year)

Item	Generation	Agriculture Reuse	landfill	Incineration	Ocean	Yards	Other
Korea*	1,411	34(2.4)	793(56.2)	21(1.4)	552(39.1)	-	13(0.9)
Japan**	1,710	233(13)	1,037(61)	-	-	-	440(26)
U.S.A.***	5,357.2	1,784.8(33.3)	2,372.2(44.2)	864.7(16.1)	335.5(6.3)	-	-
Austria	170	30.6(18)	59.5(35)	57.8(34)	-	22.1(13)	
Belgium	59.2	17.2(29)	32.5(55)	8.9(15)	-	0.6(1)	
Denmark	170.3	92(54)	34(54)	40.9(24)	-	3.4(2)	
Finland	150	37.5(25)	112.5(75)	-	-	-	
France	865.4	502(58)	233.5(27)	130(15)	-	-	
Germany	2,681.2	724(27)	1,448(54)	375.2(14)	-	134(5)	
England	1,107	488(44)	88.6(8)	77.4(7)	322(30)	121(11)	
Greece	4,821	4.8(10)	43.4(90)	-	-	-	
Ireland	36.7	4.4(12)	16.6(45)	-	12.8(35)	2.9(8)	
Italy	816	269.2(33)	449(55)	16.2(2)	-	81.6(10)	
Luxemburg	8	1(12)	7(88)	-	-	-	
Netherlands	335	87(26)	171(51)	10(3)	-	67(20)	
Norway	95	53.2(58)	41.8(44)	-	-	-	
Portugal	25	2.7(11)	7.3(29)	-	0.5(2)	14.5(58)	
Spain	350	175(50)	122.5(35)	17.5(5)	35(10)	-	
Sweden	200	80(40)	120(60)	-	-	-	
Swiss	270	121.5(45)	81(30)	67.5(25)	-	-	

Ref. : * "Control and Re-use of Sewage Sludge" Advanced Environmental Technology (Mr. K.H. Kwon), 1998,
** : Recycle and Re-use (1998) (based on dry sludge), *** : U.S. EPA (1988)

The potential health hazard, posed by indiscriminate disposal of sludge containing **pathogens**, capable of causing disease such as cholera, typhoid, dysentery, hepatitis etc. in public has been proved to be real and serious.

Microorganism	Concentration per 100 ml
Coliforms	$10^{7} – 10^{9}$
Fecal Coliforms	$10^{6} – 10^{8}$
Fecal Streptococci	$10^{6} – 10^{7}$
Salmonella	1 - 100
Anaerobic spore forming bacteria	

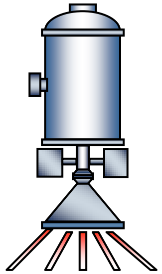


Present practices for sludge management

- **Incineration** – Energy intensive, expensive, disturbs the environmental balance
- **Landfill** – Wasteful, limited availability of land in urban areas
- **Sea disposal** – Location dependent, polluting

E- Beam Effect in Sludge Treatment

+. Sludge Hygienization

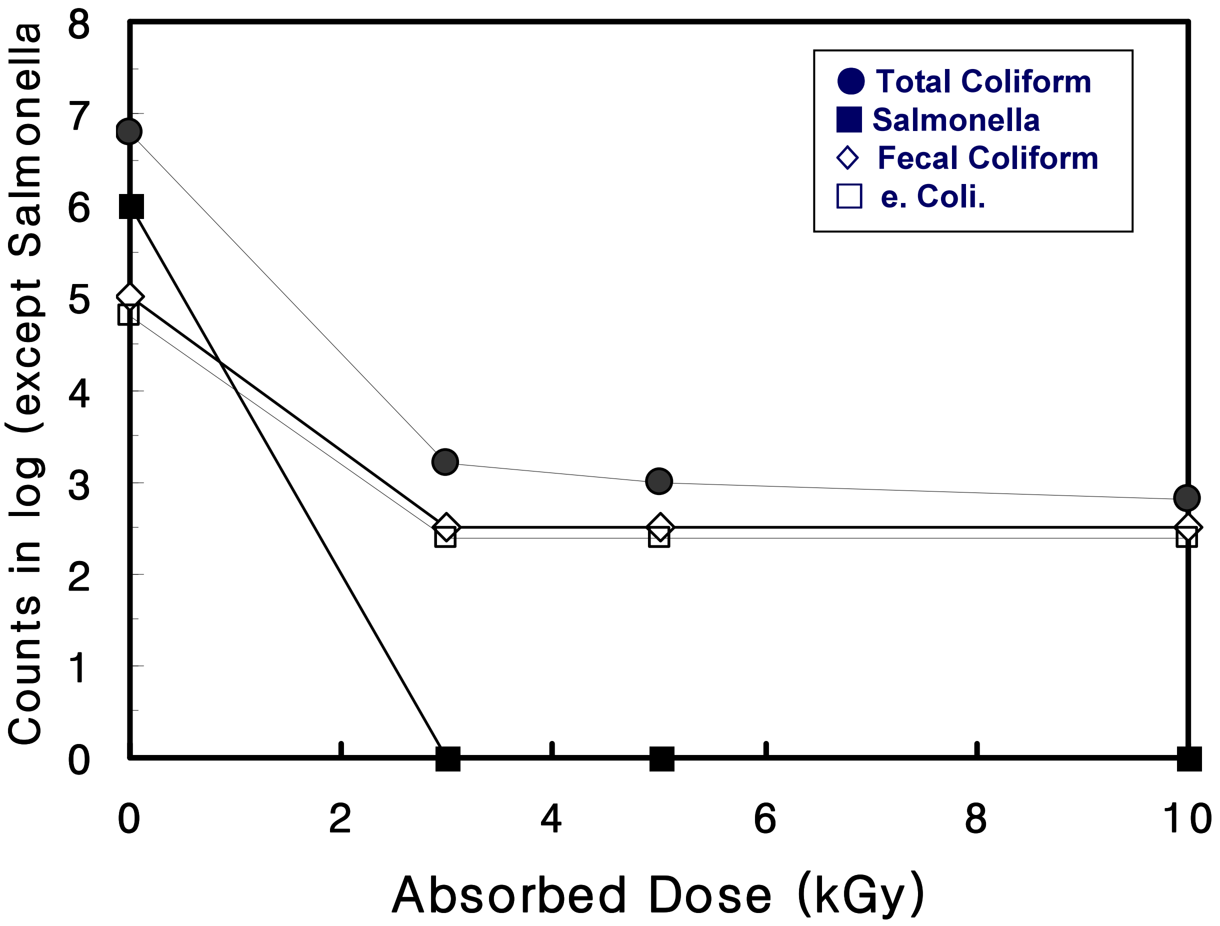


H_2O $\xrightarrow{\text{Radiation}}$ $\bullet OH$, $H\bullet$, e^-_{aq}, H_2, H_2O_2

$\bullet OH$, $H\bullet$, e^-_{aq}, + DNA of microorganism → Damage in DNA (no duplication)

Advantages of E- Beam Sludge Treatment

- Inactivation of dangerous microorganisms and parasites
- Removal of pollutants by oxidative degradation
- Elimination of toxicity, color and smell of pollutants and addition of biodegradability by changing chemical structure
- Improvement of precipitation and filtration properties of fine particles of pollutant



Survival of micro-organism population s a function of radiation dose
(beam energy :1MeV, thickness of sludge : 3mm)

The US EPA Guidelines

US Environmental Protection Agency (US EPA) guidelines have recommended that the number of E.coli, an indicator bacteria, should not exceed 1000 per gram of dry sludge for use in agricultural practices

Class A Pathogen Requirements

TABLE 5-2
Pathogen Requirements for All Class A Alternatives

The following requirements must be met for ***all*** six Class A pathogen alternatives.

Either:

the density of fecal coliform in the biosolids must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis),

or

the density of *Salmonella* sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

Either of these requirements must be met at one of the following times:

— when the biosolids are used or disposed;

— when the biosolids are prepared for sale or give-away in a bag or other container for land application; or

— when the biosolids or derived materials are prepared to meet the requirements for EQ biosolids (see Chapter 2).

Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment, percent solids vector attraction, injection, or incorporation options are met.

TABLE 5-4
Processes to Further Reduce Pathogens (PFRPs) Listed in Appendix B of 40 CFR Part 503

1. Composting

Using either the within-vessel composting method or the static aerated pile composting method, the temperature of the biosolids is maintained at 55°C or higher for 3 days.

Using the windrow composting method, the temperature of the biosolids is maintained at 55°C or higher for 15 days or longer. During the period when the compost is maintained at 55°C or higher, the windrow is turned a minimum of five times.

2. Heat Drying

Biosolids are dried by direct or indirect contact with hot gases to reduce the moisture content of the biosolids to 10 percent or lower. Either the temperature of the biosolids particles exceeds 80°C or the wet bulb temperature of the gas in contact with the biosolids as the biosolids leave the dryer exceeds 80°C.

3. Heat Treatment

Liquid biosolids are heated to a temperature of 180°C or higher for 30 minutes.

4. Thermophilic Aerobic Digestion

Liquid biosolids are agitated with air or oxygen to maintain aerobic conditions, and the mean cell residence time of the biosolids is 10 days at 55° to 60°C.

5. Beta Ray Irradiation

Biosolids are irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C).

6. Gamma Ray Irradiation

Biosolids are irradiated with gamma rays from certain isotopes, such as Cobalt 60 and Cesium 137, at room temperature (ca. 20°C).

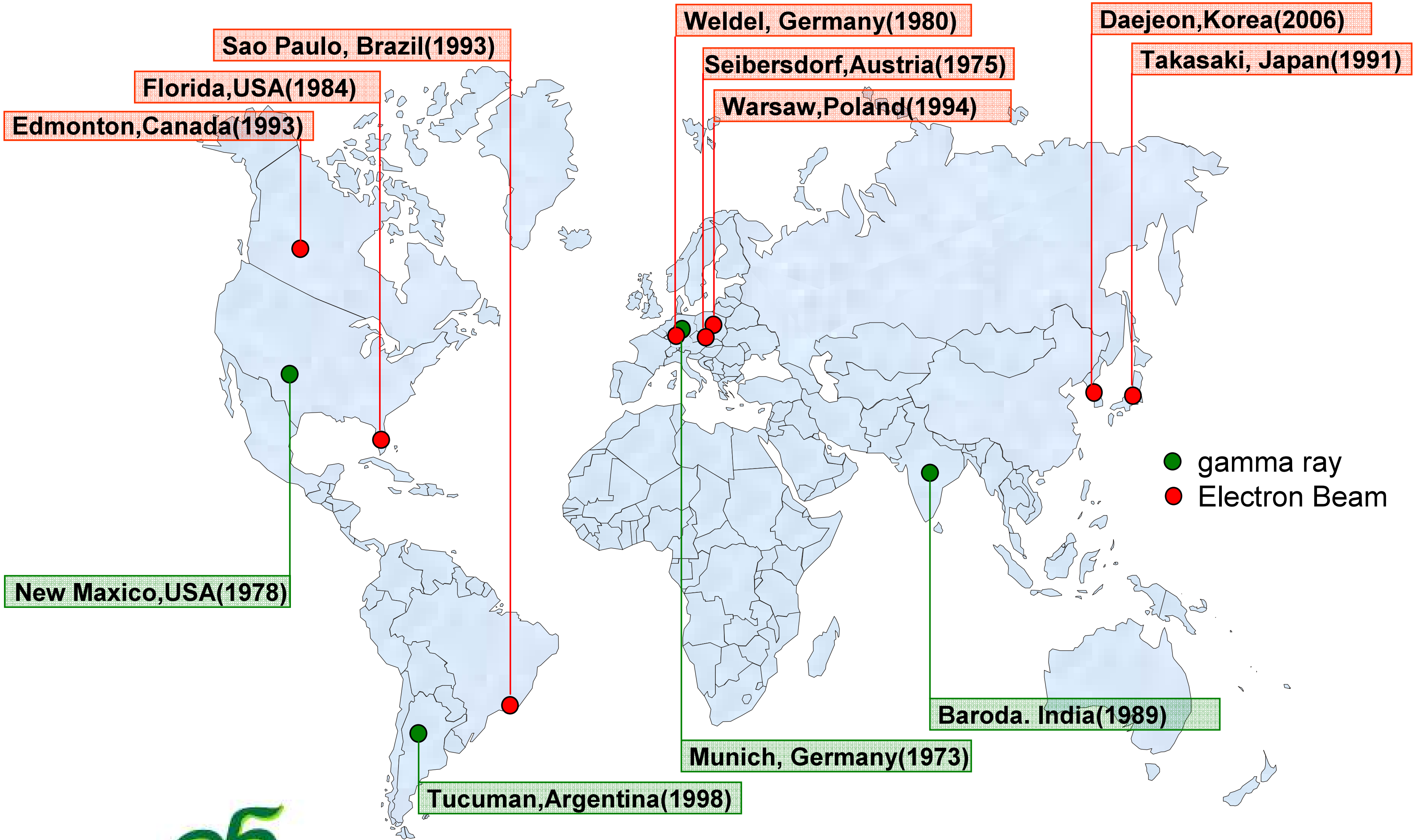
7. Pasteurization

The temperature of the biosolids is maintained at 70°C or higher for 30 minutes or longer.

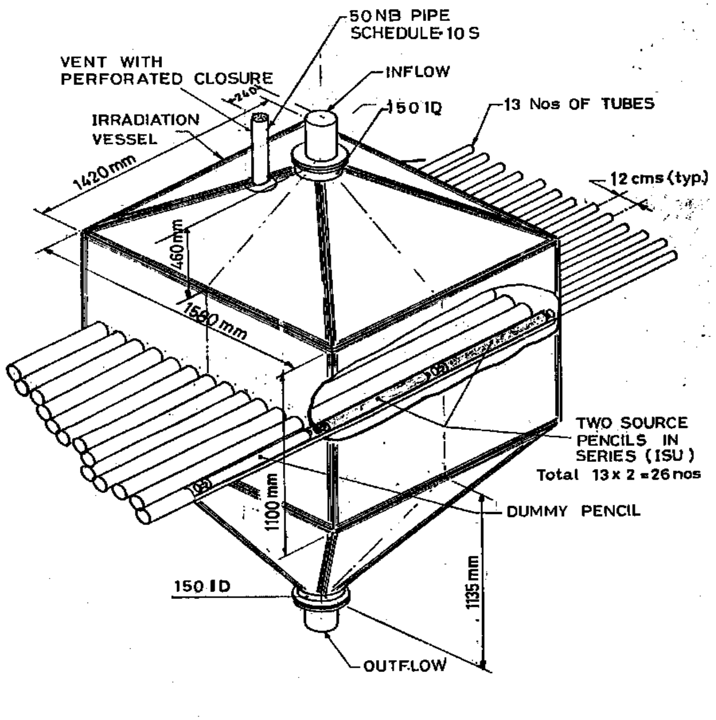
Pilot and Commercial Sludge Treatment Plant

Facilities	Irradiation Source	Irradiated material	Operation condition	Remarks
Munich, Germany (1973~1984)	Gamma-ray(60Co) 0.57Mci	Liquid Sewage sludge, 145m3/day	2-3kGy,	Commercial plant
New Maxico, USA (1978)	Gamma-ray(137Cs) 0.9MCi	Sewage sludge cake 22-90t/day	10kGy	Pilot Plant Conveyor
Vadodara, India (1989)	Gamma-ray(60Co) 0.5Mci	Liquid Sewage sludge, 110m^3/day(4%SS)	3-5kGy	Commercial plant
Tucuman, Argentina (1998)	Gamma-ray(60Co) 0.7Mci	Liquid Sewage sludge, 180m^3/day(8-10%SS)	3kGy	
Weldel, Germany (1980)	Electron beam 50kW(1.0MeV, 50mA)	Liquid Sewage sludge 500m^3/day	4kGy	Incline plan reactor
Verginia Key Florida, USA(1984)	Electron beam(ICT type) (75kW/1.5MeV/50mA)	Liquid Sewage sludge, 645m^3/hr, 4%ss	4kGy 10mm-thick	Pilot plant
Takasaki, Japan (1991)	Electron beam (Cockcroft-walton) (15kW/2MeV/15kW)	Sewage sludge cake 300kg/h	5kGy 1-10mm thick	Conveyor/Nozzle
Sao paulo, Brazil (1993)	Electron beam 25kW(1.5MeV, 25mA)	Liquid Sewage sludge 3m^3/hr	3kGy	Pilot Plant
Warsaw, Poland (1994)	Electron beam(LAE13/9) (10MeV, 15kW)	Sewage sludge cake, 70t/day	5-7kGy 2-3cm thick	Design Works
Daejeon, Korea (2005)	Electron beam 40kW(1.0MeV, 40mA)	Dewatered Sludge	1~3kGy 6mm thick	Pilot scale

Sludge Treatment Plant in the World



Gamma ray Sludge Hygenization Plant_at Vadodara



THE SOURCE FRAME INSIDE THE IRRADIATOR

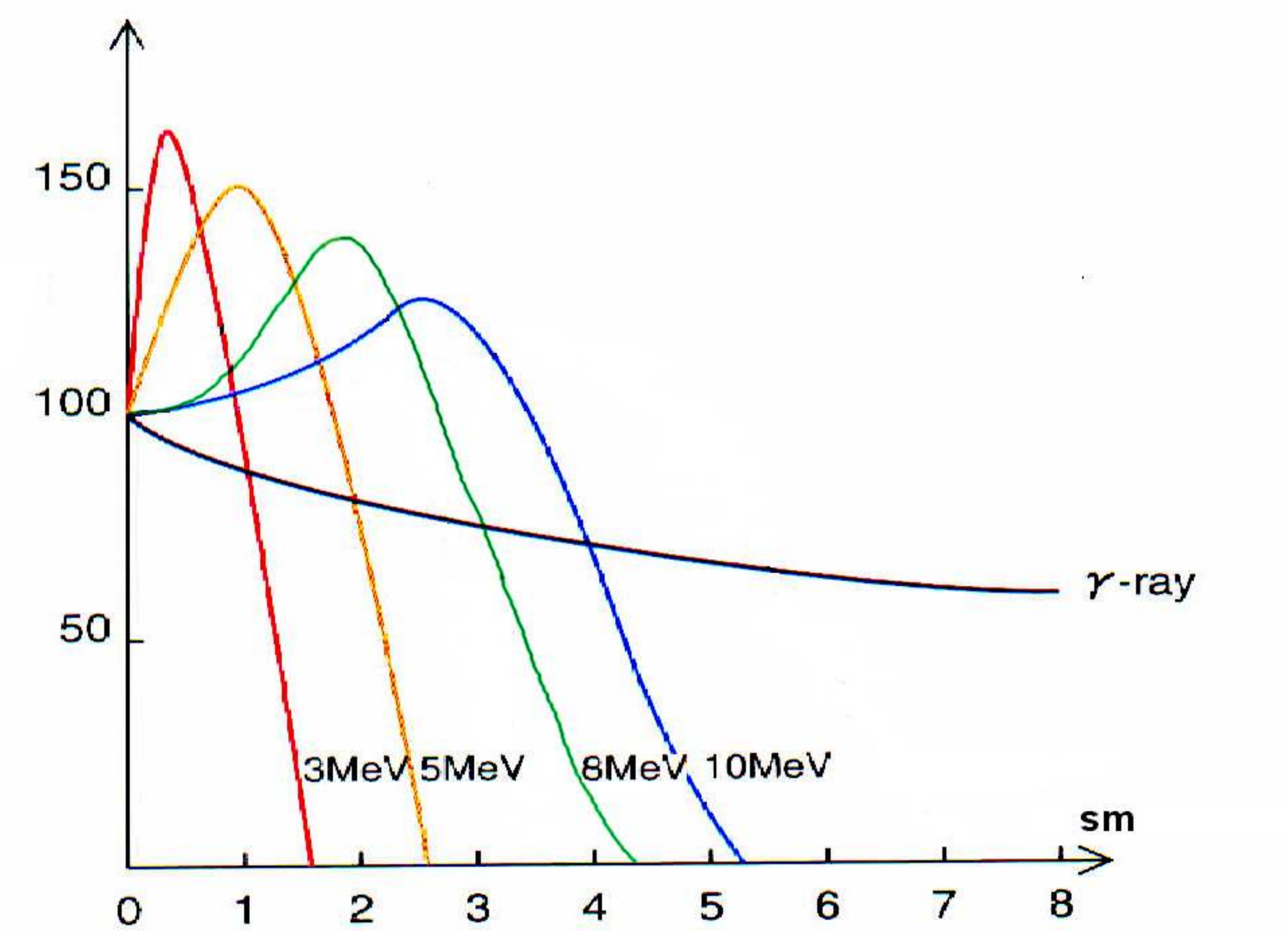
S. SABHARWAL, M.R. SHAH, N. KUMAR, J.B.PATEL, Technical and Economical Aspects of Radiation Hygienization of Municipal Sewage Sludge Using Gamma Irradiator, Reports of Consultants' meeting on Radiation Processing of Gaseous and Liquid Effluents, (2004) IAEA

Why e-beam Sludge Treatments are not widely used ?

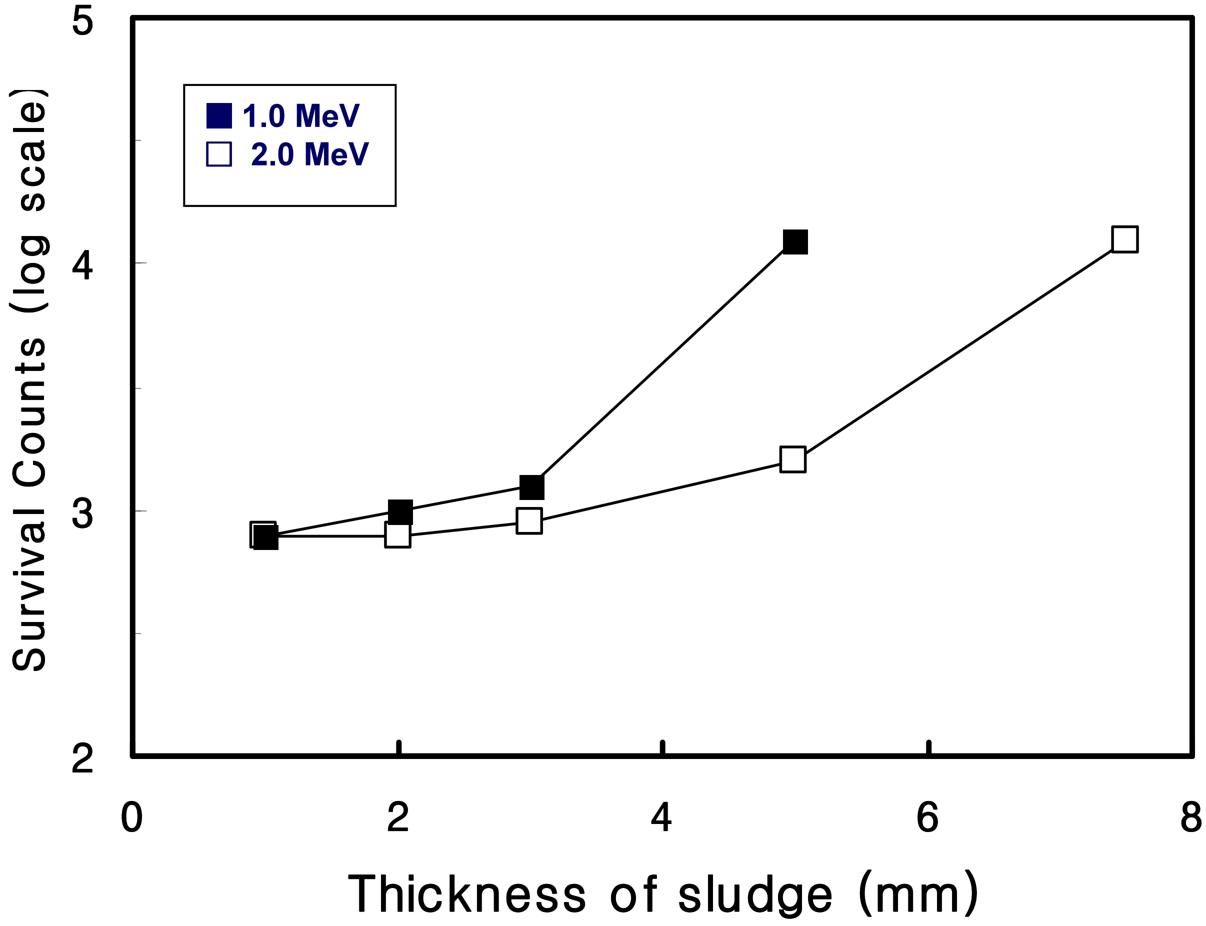
General Barriers for Environmental Application

-. Public Acceptances

-. Technical problems Penetration depth, Sludge delivery system

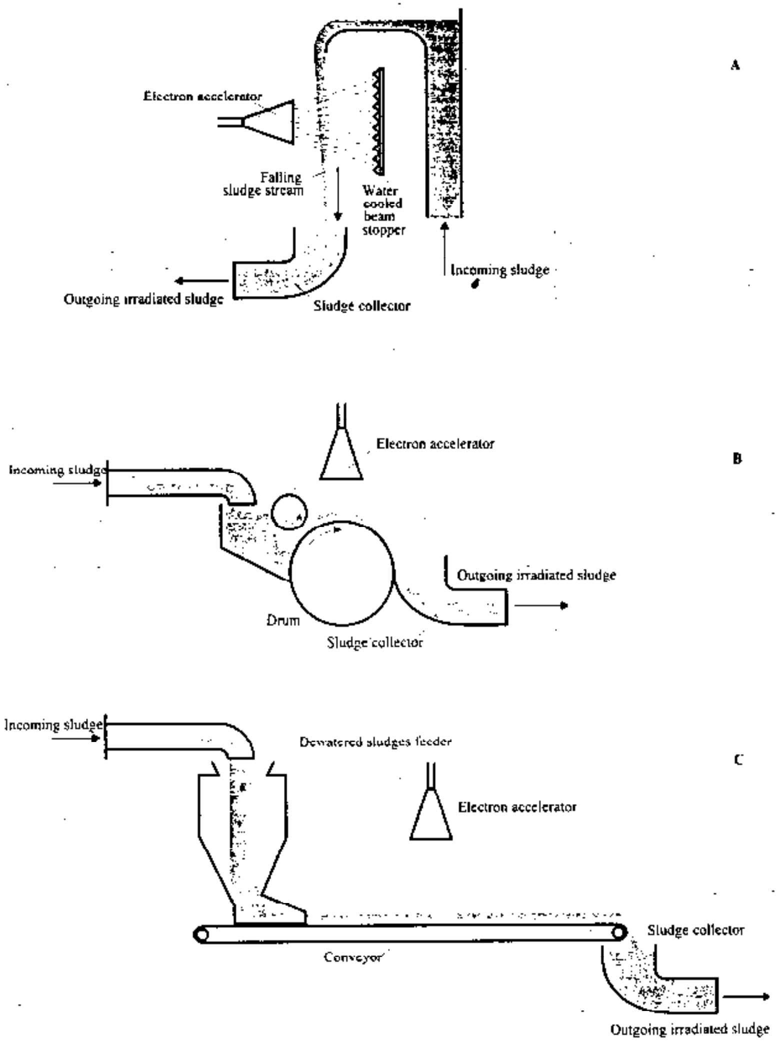


Dose distribution of electron beams in water



Survival of micro-organism population as a function of electron energy
(total coliforms at 10kGy)

Reactor Types

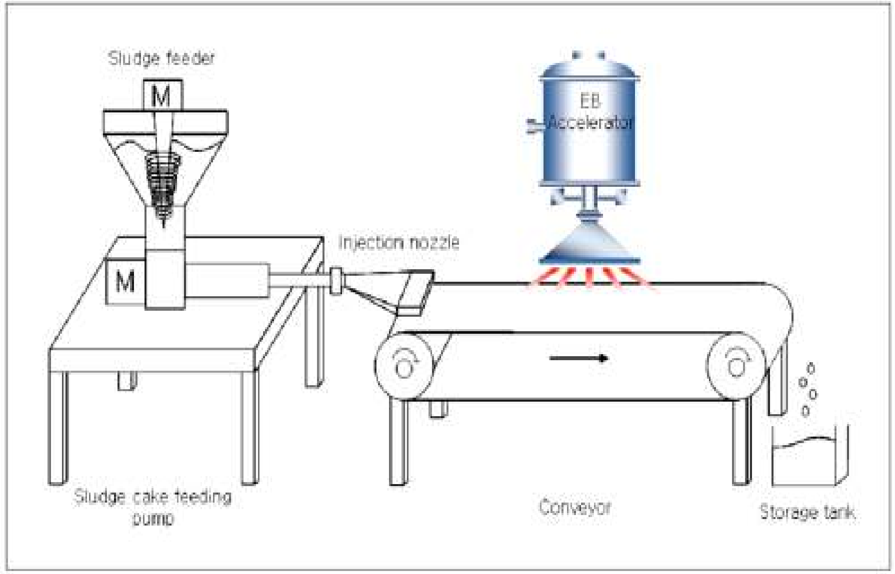


Water fall type
-Liquid sludge
-Boston, U.S.A

Clumping problem

Drum type
-Liquid sludge
-Boston, U.S.A

Conveyor type
-Dewatered sludge
-EB-Tech, Korea
-Takasaki, Japan


Sludge feeder
M
EB
Accelerator
Injection nozzle
M
Sludge cake feeding
pump
Conveyor
Storage tank

Why e-beam Sludge Treatments are not widely used ?

General Barriers for Environmental Application

-. Public Acceptances

-. Technical problems

Penetration depth, Sludge delivery system
Heavy metal, Re-growth of micro-organism

Heavy Metals

Maximum permitted concentrations of heavy metals in sewage sludge for land application

(mg/kg dry solids)

	Netherland	France	Sweden	Japan	Korea	NSW
As	10	-	-	50	50	15
Hg	5	10	8	2	2	10
Cd	5	40	15	5	5	8-20
Cr	500	1,000	1,000	-	300	500
Pb	500	800	300	-	150	500
Ni	100	200	500	-	50	100
Zn	2,000	3,000	10,000	-	900	1,800
Cu	600	1,000	3,000	-	500	1,200

	As	Cd	Hg	Pb	Cr	Cu	Zn	Ni
Content	25	2	ND	34	80	366	756	45

(sewage sludge in Korea)

Why e-beam processes are not widely used ?

General Barriers for Environmental Application

-. Public Acceptances

-. Technical problems

Penetration depth, Sludge delivery system

Heavy metal, Re-growth of micro-organism

-. Regulation from Authorities

-. Competition with Other processes (Economics)

Competition with the conventional processes
(such as incineration, lime-stabilization)
High investment cost and long returns
Relatively high doses are required
→ Difficult to find BP

Sewage Sludge Treatment (ISRAEL)

Shafdan Wastewater Treatment Plant

Calculation of Required e-beam

<Design criteria>

- Application : Directly applied to land application of disinfected digesting sludge
- Flow rate of **Dewatered Sludge : 7,000m^3/month**
- Absorbed Dose : **2~10kGy** (depend on removal efficiency of total coli-forms bacteria. We investigate that a dose of 10kGy is sufficient to get rid of E-coli and other coli-forms in case of dewatered sludge-**18%SS**)
- Energy Absorption Efficiency = 70% (min. 60% ~ max. 80%)
- Electron Energy = max. **2.0MeV** (1.0~2.5MeV)
- Operating Time = based on **16hrs/day (@ 20days/month)**

1) Sludge amount

- Specific gravity = (1.6*0.18+1*0.82) = 1.108
- Sludge weight =1.108ton/m^3*7,000m^3/mon * 1mon/20day

  =387.8tons/day
- Treating amount (@ based on 10hrs/day, 20days/month)

$$= \frac{332.4 * 10^3 \text{ kg}}{16\text{hr/day} * 3600\text{sec/hr}} = \textbf{6.73 kg/sec}$$

2) Power of Accelerator

$$P = \frac{\text{Amount of sludge (kg/sec) * Dose (kGy/kg, kJ/kg)}}{\text{efficiency of energy transfer from accelerator}}$$

$$P = \frac{6.73 \text{ kg/sec} * 10 \text{ kJ/kg}}{0.7} = \frac{67.3 \text{ kJ/sec} (= 67.3 \text{ kW})}{0.7} = 96\text{kW}$$

∴ Required Power ≈ **100 kW**

3) Energy of Accelerator

- Porosity of cake = 30% (estimated)
- Maximum penetration depth = around 9mm (@ 2.0MeV)
- Effective depth = **7mm (@2.0MeV)**

4) Process reactor

- Conveyor type : Stainless Steel belt conveyor
- Inlet Nozzle : 1800mm(W) * 7mm(H)
- Inlet Velocity : 38.5m/min

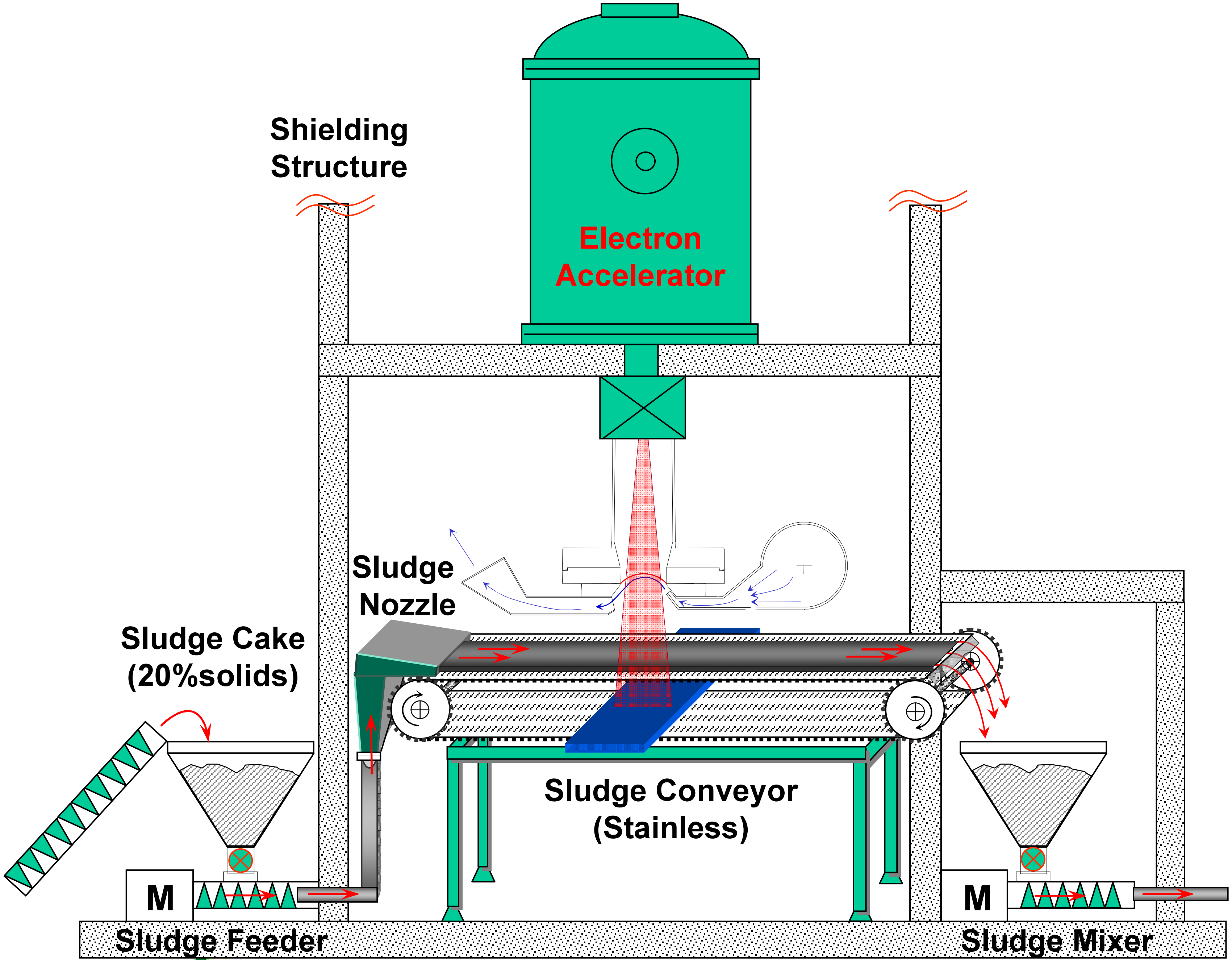
$$= \frac{7000\ m^3/mon * 1mon/20day}{16hr/day*60min/hr*(1.8*0.007m^2)} = 28.9\ m/min\ (\mathbf{30\ m/min})$$

5) Shield Room

- Material : Concrete structure , - Thickness : ~2.0 m

Item	Cost (USD)	Remarks
Capital Cost	**1,920,000**	
- E.B Accelerator	960,000	ELV-8 (2.0MeV, 100kW)
- Shielding Room	450,000	Concrete structure
- Sludge Handling System	350,000	Conveyor system/lime Handling
- Others	160,000	
Annual Fixed Cost	**288,000**	Dose = 10kGy
-Depreciation	192,000	10years
-Interest on capital	96,000	5% of capital
Annual Operation Cost	**120,000**	
-Salaries	40,000	2persons*1shift
-Utilities	60,000	Electric power(150kW)
-Maintenance	20,000	1% of capital
Total Annual cost	**408,000**	7,000m^3/mon (18%SS)
Unit Operation Cost ($/ton)	**4.4** **(2.2)**	93,000 tons/yr (at 7,000m^3/mon) 209,000 tons/yr (at 15,750m^3/mon)

Item	Plant (10kGy)	Remarks
Amount of Sludge	7,000 m^3/month	Maximum Capacity ≈ 15,750m^3/mon at 24hr/day, 30days/mon, 22m^3/hr
Sludge conditions	Wet sludge (18% solid)	
Operating Condition	16hr/day, 20days/mon, 22m^3/hr	
Required Power	100kW	Power consumption 150kW including pumps and other equipments.
Nozzle size	7mm (H) (for 2.0MeV) 1800mm (W)	S/S Nozzle and feeder
Conveyor Speed	30m/min	S/S Conveyor
Recommended Accelerator	2.0MeV, 100kW	- ELV-8
Capital cost ($)	USD 1,920,000 -. 960,000 (Accelerator) -. 960,000 (Civil works, handling)	+ Lime Handling System + Electric Power Supply & Cabling + control room, Aux. Equipment etc.
Operation cost ($/ton)	4.4 USD/ton	- Reduced to 2.2 at Max. capacity


Shielding Structure
Electron Accelerator
Sludge Nozzle
Sludge Cake (20%solids)
M
M
Sludge Conveyor (Stainless)
Sludge Feeder
Sludge Mixer

Electron Beam Sludge System

Proposed Process

Dewatering Sludge → **EB Irradiation** → **Lime or Inoculation** → **Agriculture Use**

(Volume Reduction) (Disinfection) (Reduce Smell and Stabilization) (Fertilizer)

Unit Cost

EB(4.4) + Lime[1] or Inoculants (2.3~3.2) + Handling[2] (10) = 16.7~17.6$/ton

Note)

1) Required Lime Amount(@ Lime Price: 75~80$/ton, Solids content = 20%)

- Without EB : 100~133kg Lime/ton of dewatered sludge(7.5~10.6$/ton)
- With EB : 30 ~ 40kg Lime/ton of dewatered sludge(2.3 ~ 3.2$/ton)

2) Handling (Mixing, Transportation and Spreading) cost = 10$/ton (estimated)

Summary

1. Electron Beam Process is a quick and credible method of hygienization of municipal sewage sludge.

2. Sludge hygienized with e-beam can be used as soil fertilizer immediately after treatment and no large land areas are needed to their disposal for long time.

3. The operation cost of e-beam sludge plant is around 4.4 USD for each ton (2.2 USD at Max. capacity) and more convenient and competitive to other technologies.

Thank You for your attention

Electron Beam Technology

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