RADIATION HYGIENIZATION OF RAW SEWAGE SLUDGE

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Abstract. Radiation treatment of municipal sewage sludge can achieve resource conservation and recovery objectives. The liquid sludge irradiator of Sludge Hygienization Research Irradiator at Baroda (India) was operated for generating data on treatment of raw sludge containing 3-4 % solids. The plant system was modified for irradiating raw sludge without affecting basic irradiator initially designed to treat digested sludge. Hourly samples were analysed for estimation of disinfection dose requirement. Sand separated from the sludge was used as in-situ dosimeter by making use of its thermoluminescence property. Investigations are being carried out for regrowth of Total Coliforms in the sludge samples from this irradiator. Possibility of inadequate treatment due to geometric configuration of irradiator is being checked.

1. INTRODUCTION

Production of municipal wastewater and sludge has reached alarming dimensions with the growth of urban population all over the world. Conventional methods of separation and biological treatment of sludge allow its return to environment by disposal in ocean or landfill. Several technologies such as heat pasteurization, lime application, prolonged storage, composting and curing are recommended to achieve additional inactivation of microorganisms beyond that attainable by conventional sludge stabilization methods [1].

Conventional methods for treatment of wastewater are directed towards removal of pollutants with the least effort. Primary treatment includes screens, grit chambers, gravity sedimentation and chemical precipitation. Secondary treatment is designed to remove colloidal and soluble organics through biological treatment. Aerobic and/or anaerobic digestion processes are carried out in lagoons, trickling filters, activated sludge systems, closed anaerobic digestor tanks and other similarly large equipment [2].

Wastewater and sludge treatment plants use sedimentation and biological stabilization mainly to save energy and running costs. Depending on climatic conditions, problems of growth of algae and aquatic weeds, mosquito breeding, release of obnoxious gases, etc. are associated with the conventional plants. The sludge requires stabilization even after anaerobic digestion. Composting, heat pasteurization or incineration is employed and the inert product is then returned to the environment by way of landfill or ocean dumping.

Municipal sewage sludge is a very rich source of plant nutrients and soil conditioners. Land spreading can become popular in agricultural areas. Nutrient release with sludge is slower than with chemical fertilizers, allowing the nutrient to become available as the crop needs it. The sewage sludge makes an excellent soil conditioner because the humus material provides a good matrix for root growth, while nutrient release is in a right combination for optimal plant growth. Land spreading of sludge requires careful application. Soil microbes will assist in further stabilization of organics. Its reuses are beneficial as energy and nutrients are becoming scarcer [2].

Radiation treatment of sludge reduces pathogenic bacteria to a safe level. It also oxidizes toxic and hazardous organic chemicals [3]. It reduces odour nuisance. The treatment of sludge is achieved in simple, efficient and reliable way with radiation equipment.

Studies undertaken for disinfecting raw sludge with radiation at SHRI Facilities, Baroda would provide useful data as to utilize radiation technology for environmental conservation.

2. SCOPE AND OBJECTIVES OF THE RESEARCH PROJECT

The programme of work under this CRP was specified initially, as follows:

- modification of irradiation plant in order to irradiate raw sludge (3-4 % solid);
- irradiation at different conditions and determination of chemical and microbiological change in sludge;
- analysis and comparison of data with irradiation of digested sludge.

Further research work was assigned in extended projects, as follows:

- collection of more data on the seasonal variations of coliforms to arrive at the required dose for hygienization;
- study of regrowth of bacteria in detail, possibility of inadequate treatment due to geometric configuration of source and attached piping system will be checked;
- post irradiation treatment techniques such as; inoculation of useful bacteria with irradiated sludge and/or irradiation followed by rapid dewatering will be employed;
- combined action of radiation and sensitizers such as oxygen, hydrogen peroxide, heat will be investigated.

The programme goals should be directed to establish the following [4]:

- optimal combination treatment for wastewater and sludges;
- effects of dose rates on decontamination efficiency;
- dosimetric procedures;
- technological and economic parameters.

3. SPECIFICATIONS OF SHRI IRRADIATOR, BARODA (INDIA)

With the aim of demonstrating appropriate radiation technology for treating the entire sludge generated from the 5 MGD (22000 m^3/d or 22 ML/d) conventional municipal treatment plant, the facility was set-up by the Isotope Division of the Bhabha Atomic Research Centre in collaboration with M.S. University of Baroda, Gujarat Water Supply & Sewerage Board and Municipal Corporation of Baroda. The main technical specifications of the SHRI Facility were the following:

— sludge treatment capacity (max.)	110 m^3/d
— maximum ^{60}Co activity	18.5 PBq (500 kCi)
— biological shield capacity	37 PBq (1000 kCi)
— treatment dose	Variable 0.5–5 kGy (50-500 kRad)

Sludge Hygienization Research Irradiator (SHRI) Facility is integrated with the existing conventional plant serving a population of about 0.3 million inhabitants. Since its commissioning in 1990, with an initial charge of 5.5 PBq of ^{60}Co, the plant is continuously in operation and working smoothly. Current ^{60}Co source strength is about 1.76 PBq, which corresponds to the processing rate of approximately 10 m^3/d of sludge.

Sludge Hygienization Research Irradiator (SHRI) Facility is integrated with 5 MGD (22000 m^3/d or 22 ML/d) conventional plant. Since it's commissioning in 1990, it is in daily operation and working smoothly.

4. RAW MATERIAL CHARACTERIZATION

Raw sludge from the primary sedimentation tank of the conventional treatment plant is drawn to SHRI for experiments. The circular conical bottom 150 ft dia tank receives raw sewage after screens and grit chamber. The solid content in the settled sludge drawn from the bottom was found to vary between 2 to 7 % by weight. Non-homogenized fibrous material and other floating particulate matters were also allowed to mix with this sludge. Raw sludge is associated with the presence of foul odour due to high content of volatile gases. Usually this is treated in the anaerobic digestors.

5. MODIFICATIONS IN THE IRRADIATOR SYSTEM

As part of this research project, following modifications in the irradiation plant at Baroda were necessary to irradiate raw sludge directly from the primary settling tank.

(1) Cast iron pipeline of 4" NB size for pumping sludge from primary settling tank to receiving tank of SHRI was commissioned. The connection with a valve was branched off existing pipeline for pumping raw sludge to digestors. By co-ordination with staff of municipal treatment plant, raw sludge is made available to irradiation facility.

(2) A screen made of G.I. wire mesh (25 mm openings) of 3 m height and 2 m width was installed in the receiving tank. Filtering out large sticky objects and fibrous materials has reduced problems in operation of pumps and piping, while filling the irradiation vessel. Frequent cleaning of this screen is carried out manually.

(3) Use of metering silo for sludge is discontinued to decrease pump discharge head. The silo located above the irradiator was used to control volume of sludge to be irradiated in the irradiator vessel. Alternate method of level control by use of nucleonic level gauge as well as visual indication is provided. Difficulties in pumping of raw sludge from underground receiving tank with a self-priming sludge pump were anticipated due to presence of non-homogenized solid and high volatile contents of undigested sludge.

6. DESCRIPTION OF EXPERIMENTAL METHOD

Raw sludge is drawn from the primary settling tank into a 10 m^3 underground receiving tank. For each batch of experiments 3 m^3 of sludge is pumped into an irradiator vessel, which takes about three minutes. Recirculation and aeration are commenced soon after attaining the level in the irradiator vessel. Recirculation rate of 1 m^3/min is achieved by a centrifugal sludge pump. This assures mixing and uniform absorbed dose in sludge and deposition free operation of piping. Aeration within the irradiation zone is provided by compressed air monitored by flowmeter giving 0-100 lit/min of air. Samples for analyses are drawn from recirculation line outside irradiation cell area with the help of stainless steel ball valve arrangement. After completion of batch experiment the treated sludge is drained under gravity to either sand bed for drying or to the facility garden. The process is repeated for the next batch.

7. TL DOSIMETRY FOR SLUDGE IRRADIATION SYSTEM

In our earlier work for dosimetry for the digested sludge disinfection at the SHRI irradiator, it has been shown that sand separated from the sludge can be used as an in situ dosimeter by making use of its thermoluminescence property [5, 6]. The method is usable for estimating dose delivered to the samples in the dose range of 0.25 to 4 kGy.

A minimum of 15 litres of liquid sludge was collected from the receiving tank of SHRI irradiator for calibration. Experimental samples were collected from the same batch of sludge after an interval of two hours. The total irradiation period was six hours. These samples were allowed to settle. The settled portion of the sludge was collected and washed with water repeatedly. Carbonates from the sample were removed by treating with 1N HCl (hydrochloric acid). After cleaning with water, hydrogen peroxide (H_2O_2)(30 %) was added to remove the organic matter. Almost all the organic material could be removed by repeating this process twice or three times. After complete removal of organic material, the sand was separated and cleaned repeatedly with distilled water. The cleaned sample was dried at room temperature.

Magnetic particles and mica were removed from the sample by magnetic and electrostatic separation, respectively. After drying, particles in the size range 75–125 μm were collected using standard test sieves. A part of the above sample was further treated with hydrofluoric acid (40% concentration) in a Teflon beaker for one hour. Immediately after decantation of hydrofluoric acid (HF), concentrated HCl (12 N) was added to the beaker to remove fluorides. Finally, this was cleaned repeatedly with distilled water and quartz was separated.

For calibration, the quartz samples collected from the inlet of the irradiator were irradiated in a dose range of 0.25 kGy to 8 kGy using gamma chamber at a dose rate of 10.01 Gy/min. Care was taken to protect the sand samples from exposure to light (from sun as well as from room lighting) during collection, cleaning, irradiation and TL readout of sludge samples, as they show light-induced TL fading. All the TL measurements (peak height as well as area under the TL glow peaks) on the samples were taken at a heating rate of 10°C/s, using a Harshaw 3000A TLD reader coupled to a flow chart recorder. For each measurement, 5 mg of sand sample was used.

The absorbed doses in the sludge for three different periods of irradiation were estimated by using 220°C and 370°C TL peaks (differential as well as integral TL methods) of these samples (five readings each) as of 11 June 1997.

The results are summarized in Table I.

TABLE I. ESTIMATION OF DOSE RATE BY TL METHODS

Period of irradiation in hour	Estimated absorbed dose in kGy	
	220°C	370°C
2	0.96 ± 0.04	1.00 ± 0.05
4	2.00 ± 0.06	2.00 ± 0.06
6	3.00 ± 0.04	3.00 ± 0.02

The average dose for two hours of irradiation was estimated to be 0.993 ± 0.03 kGy. This value of dose rate (i.e. 0.5 kGy/h) is considered for current estimation of absorbed dose during irradiation of raw sludge in SHRI irradiator.

8. MICROBIOLOGICAL ANALYSES OF RAW SLUDGE IRRADIATION

Microbiological analyses of raw sludge were carried out for estimating decontamination efficiency of radiation treatment. Hourly samples were taken for analyses. Plate count methods of analysis were employed for determination of colony forming units per ml of Total Coliforms, Total Salmonella-Shigella and Total Bacteria using appropriate agars. The effect of aeration during irradiation was also studied.

Table II shows Total Coliforms data obtained in these experiments. Experiments numbered from 1 to 16 are without aeration batches. Remaining batches are processed using compressed air bubbling in the irradiation vessel during recirculation. The recirculation flowrate during the experiments was observed to be 50 to 70 m^3/hr.

The data for coliform is graphically represented in Fig. 1. Figure 2 is prepared by plotting the average of coliform reductions in respective experiments in log units v/s irradiation time (which is proportional to absorbed dose), which explains the effect of aeration during radiation treatment.

TABLE II. RAW SLUDGE IRRADIATION (PLATE COUNT METHOD) — TOTAL COLIFORMS

Expt No.	Date	Aeration lit/min	% Solids (by wt.)	Total Coliforms in cfu/ml Irradiation Time in hours							
				0	1	2	3	4	5	6	7
1	17/10/96	0	3.50	8300	300	0	30	20	90	370	
2	29/10/96	0	1.10	17600	100	0	0	10	0	0	
3	18/11/96	0	5.00	306000	85	36		13	3	3	5
4	26/12/96	0	2.00	102000	1100	100	2	10	1		
5	03/01/97	0	4.00	207000	18000	3200	560	61	24	15	
6	10/01/97	0	5.00	42000	17600	2600	230	68	51	126	
7	21/01/97	0	3.10	8700	240	40	102	74	87	84	
8	02/04/97	0	0.90	90000				66			
9	17/06/97	0	0.73	212000						50	
10	02/07/97	0	5.04	113000						8	
11	03/07/97	0	1.80	179000						8	
12	02/06/97	0	5.04	680000						8	
13	23/09/97	0	4.50	195000	930	89	56	40	25	17	
14	24/09/97	0	4.37	154000	675	106	64	38	23	7	
15	25/09/97	0		116500	820	96	55	51	27	10	
16	08/10/97	0	2.86	44000	975	189	38	59	13	14	

TABLE II. (cont.)

Expt No.	Date	Aeration lit/min	% Solids (by wt.)	Total Coliforms in cfu/ml Irradiation Time in hours							
				0	1	2	3	4	5	6	7
17	15/10/96	2	2.80	13600	1500	200	32	0	6		
18	24/10/96	2	2.80	29000	0	0	0	0	10	20	
19	22/11/96	2	7.86	98000		5440		0	68	38	124
20	12/12/96	4	3.26	47500		340		12		3	
21	31/12/96	5	6.40	126000	20500	1680		28	18	21	
22	07/01/97	5	3.91	8500	360	4	8	1	5	0	
23	17/01/97	5	5.00	20000	660	90	52	44	28	45	
24	30/01/97	5	2.24	26900	220	10	9	13	24	39	
25	21/02/97	5	2.20	220000				142			
26	26/08/97	7	0.59	2800	106	520	208	12			
27	02/09/97	7	3.04	72000	1410		28	8	6	6	
28	04/09/97	7	3.82	93000	142	100	36	8	8	18	
29	28/11/96	8	3.60	32000	200	20	20	0	10	27	19
30	28/08/97	9	3.93	90000	1500	116	40	22	8	4	
31	04/04/97	10	1.43	720000		152				50	
32	06/05/97	10	2.21	160000						34	
33	07/05/97	10	1.07	101000						14	
34	15/05/97	10	0.95	2580						10	
35	19/05/97	10	4.56	65000						24	
36	10/06/97	10	1.86	233000						34	
37	26/06/97	12	0.80	3200						24	
38	25/06/97	14	1.42	57000						38	
39	18/06/97	18	0.71	38000						6	
40	30/09/97	100	3.33	155000	300	108	45	39	72	91	
41	01/10/97	100		35000	36	22	25	22	10	29	
42	09/10/97	100	3.02	18800	320	49	62	102	139	230	
43	16/10/97	6	3.68	520000	216	89	151	69	97	70	
44	23/10/97	4	3.55	24950	164	127	95	129	119	81	
45	5/12/97	10		2195	202	60	31	8	110	18	
46	26/12/97	7		17150	26				7		
47	2/1/98	6		3300	78	56	20	12	37	18	
48	20/1/98	8		42000	60	29	19	14	12	10	
49	23/1/98	12	1.64	10750	88	57	34	10	14	11	
50	28/1/98	18	1.89	43500	64	17	10		16	9	
51	3/2/98	8	1.56	120500	343	148	15	13	9	10	
52	10/2/98	12	0.92	121000	112	26	16	10	24	17	
53	13/2/98	12		171500	180	110	4	28	87	273	

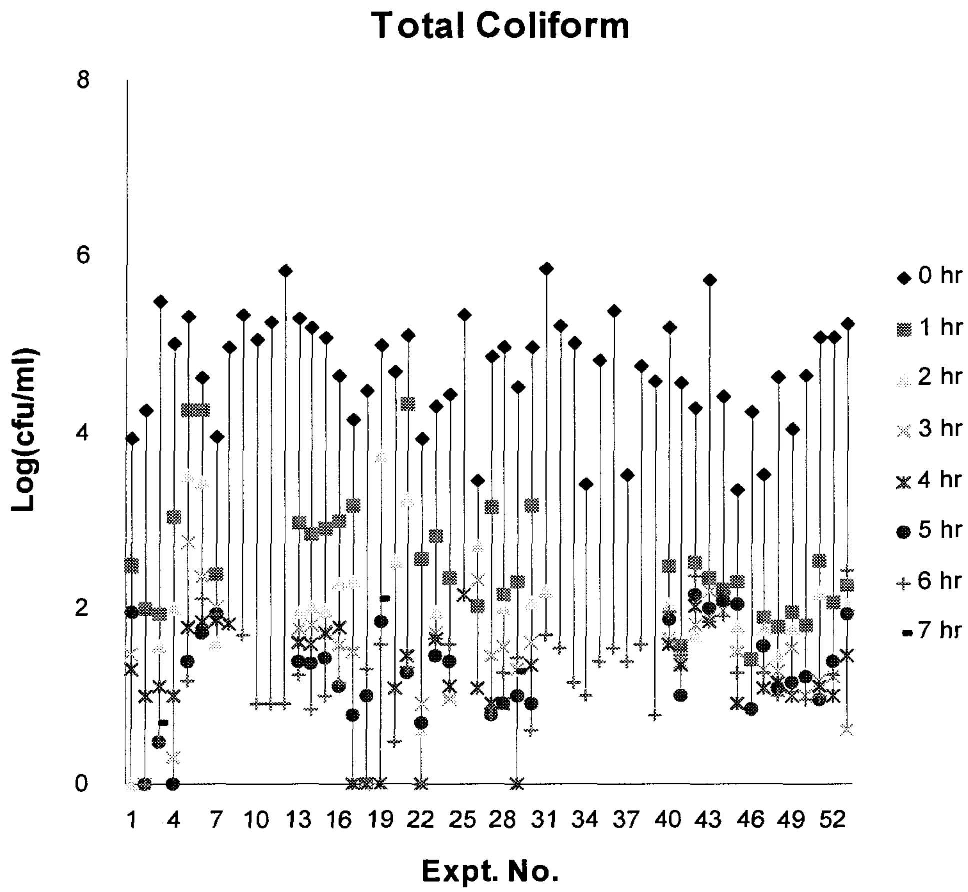

FIG. 1. Analyses of irradiated raw sludge-total coliforms.

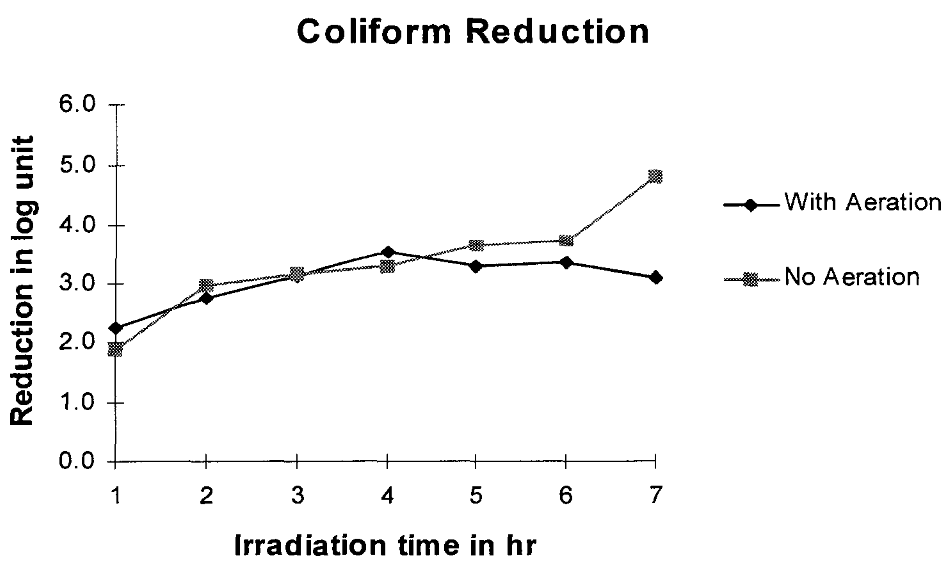

FIG. 2. Effect of aeration-total coliforms.

Analyses were also carried out to estimate reductions in Total Bacteria for some of the above experimental batches. Table III shows data for the same. Charts were prepared similarly as for Total Coliforms and presented as Figs 3 and 4.

TABLE III. RAW SLUDGE IRRADIATION (PLATE COUNT METHOD)-TOTAL BACTERIA

Expt No.	Date	Aeration lit/min	% Solids	Total Bacteria in 100 x cfu/ml Irradiation Time in hours							
			(by wt.)	0	1	2	3	4	5	6	7
1	17/10/96	0	3.50	29000	120	100	40	48	36	50	
2	29/10/96	0	1.10	16000	140	150	68	55	65	68	
3	18/11/96	0	5.00	32700	1100	264		149	116	130	107
4	26/12/96	0	2.00	38500	13	100	140	90	90		
5	03/01/97	0	4.00	88000	920	470	160	162	165	120	
6	10/01/97	0	5.00	3700	650	85	21	14	11	10	
7	21/01/97	0	3.10	25000	700	200	197	146	156	182	
8	02/04/97	0	0.90	20600				870			
9	17/06/97	0	0.73	280000						19600	
10	02/07/97	0	5.04	140000						6800	
11	03/07/97	0	1.80	70000						3400	
12	02/06/97	0	5.04	140000						6800	
13	23/09/97	0	4.50	14800	4800	4200	3800	3100	2900	1100	
14	24/09/97	0	4.37	35500	4250	2650	3550	2200	785	540	
15	25/09/97	0		53000	4550	3200	2800	1275	825	320	
16	08/10/97	0	2.86	20300	1745	880	585	440	220	133	
17	24/10/96	2	2.80	8800	156	170	109	65	25	32	
18	22/11/96	2	7.86	75000	26000	1170		182	130	88	117
19	12/12/96	4	3.26	24700		360		28		212	
20	31/12/96	5	6.40	20800	1200	250		275	180	180	
21	07/01/97	5	3.91	3000		230	300	92	163		
22	17/01/97	5	5.00	1600	1000	130	140	136	220	109	
23	30/01/97	5	2.24	1400	600	232	116	74	75	38	
24	02/09/97	7	3.04	14400	670	580	570	410	350	275	
25	04/09/97	7	3.82	34500	900	850	645	510	660	645	
26	28/11/96	8	3.60	98000	3100	1170	500	109	78	57	54
27	28/08/97	9	3.93	40000	970	790	680	540	345	290	
28	04/04/97	10	1.43	16200		640				64	
29	06/05/97	10	2.21	126000						96	
30	07/05/97	10	1.07	27900						76	
31	15/05/97	10	0.95	13200						250	
32	10/06/97	10	1.86	56000						380	
33	26/06/97	12	0.80	7800						890	
34	25/06/97	14	1.42	59000						1250	
35	18/06/97	18	0.71	9300						104	
36	30/09/97	100	3.33	73000	3850	2250	1500	405	300	590	
37	01/10/97	100		35000	16000	566	480	525	360	330	
38	09/10/97	100	3.02	9850	735	460	345	300	196	167	
39	16/10/97	6	3.68	3300	815	605	730	715	151	115	
40	21/10/97	6	6.81	237000	19000	11900	7900	7300	5200	4300	
41	23/10/97	4	3.55	1435	93	81	62	105	91	69	
42	5/12/97	10		6050	1050	245	360	142			
43	26/12/97	7		6000	3500						
44	2/1/98	6		9400	805	425	320	260	365	68	
45	23/1/98	12	1.64	161	130	114	66	57	42	41	
46	28/1/98	18	1.89	4850	640	560	240		74	39	
47	3/2/98	8	1.56	3850	1500	1150	570	345	215	100	
48	10/2/98	12	0.92	2140	445	265	230	78	51	15	
49	13/2/98	12		5250	1490	800	470	425	345	164	

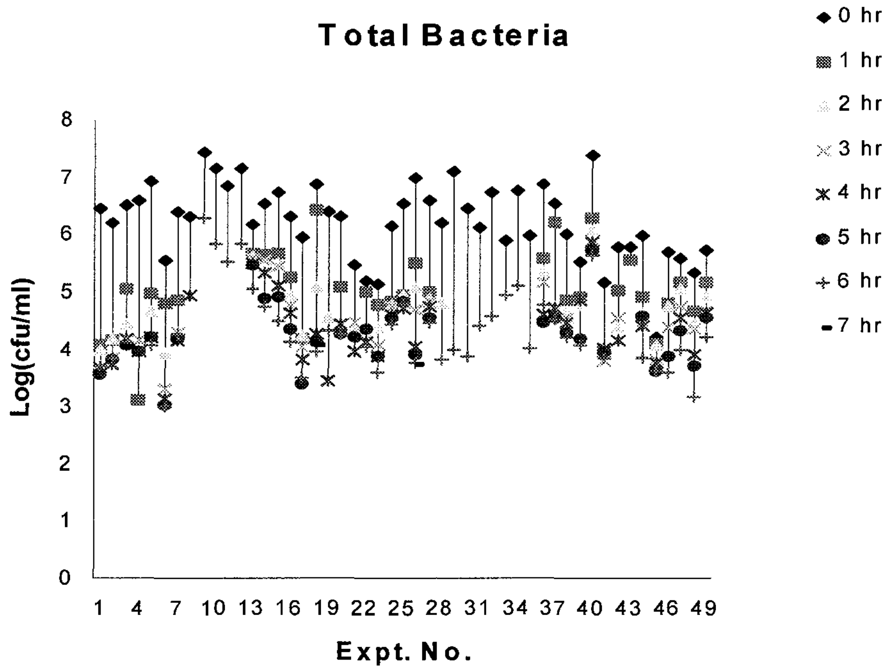

FIG. 3. Analyses of irradiated raw sludge-total bacteria.

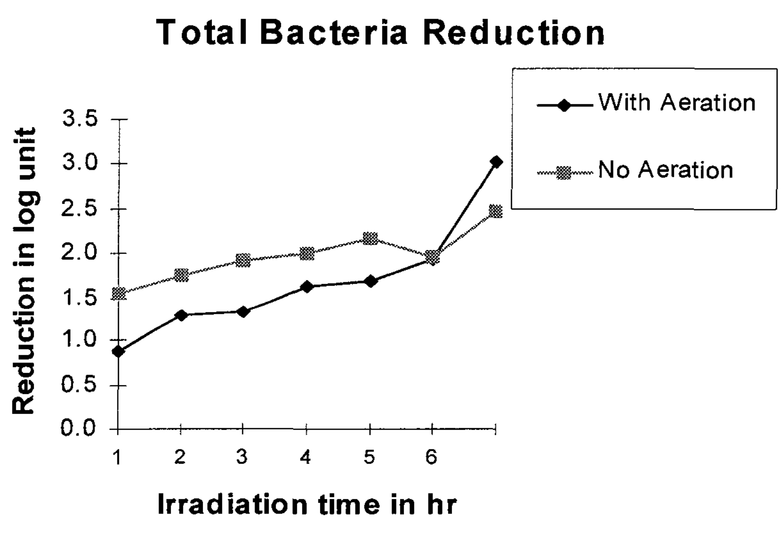

FIG. 4. Effect of aeration-total bacteria.

Total Salmonella-Shigella are considered to be pathogenic bacteria. Similar data for some of the above batches were collected. Table IV represents data for Total Salmonella-Shigella. Figs 5 and 6 are constructed from the same data.

TABLE IV. RAW SLUDGE IRRADIATION (PLATE COUNT METHOD) – TOTAL SALMONELLA-SHIGELLA

Expt No.	Date	Aeration lit/min	% Solids (by wt.)	Total Salmonella-Shigella in cfu/ml Irradiation Time in hours							
				0	1	2	3	4	5	6	7
1	17/10/96	0	3.50	5400	0	0	10	10	20	90	
2	29/10/96	0	1.10	185000	100	0	10	10	90	10	
3	18/11/96	0	5.00	2400	20	3		4	0	1	0
4	26/12/96	0	2.00	4600	100	0	7	3	0		
5	03/01/97	0	4.00	172000	1520	100	19	2	6	4	
6	10/01/97	0	5.00	30000	1940	240	23	11	11	9	
7	21/01/97	0	3.10	5600	30	4	11	8	6	15	
8	24/09/97	0	4.37	1350	42	32	18	6	5	1	
9	25/09/97	0		1210	47	24	19	12	7	1	
10	08/10/97	0	2.86	750	510	18	15	9	4	7	
11	24/10/96	2	2.80	16000	0	0	0	0	10	10	
12	31/12/96	5	6.40	13200	1100	3		1	1	0	
13	07/01/97	5	3.91	13000	220	50	5	6	5	1	
14	17/01/97	5	5.00	22000	80	20	4	10	5	8	
15	30/01/97	5	2.24	7600	120	12	15	2	11	19	
16	02/09/97	7	3.04	4150		55		0	0	0	
17	04/09/97	7	3.82	5400	16	4	4	0	0	2	
18	28/11/96	8	3.60	15000	0	0	0	4	4	4	5
19	30/09/97	100	3.33	16600	30	4	3	6	3	8	
20	01/10/97	100		7270	9	12	6	8	17	7	
21	09/10/97	100	3.02	1025	18	13	2	8	29	15	
22	16/10/97	6	3.68	140	22	13	7	2	5	12	
23	21/10/97	6	6.81	16600	1870	1550	446	375	199	111	
24	23/10/97	4	3.55	930	215	145	95	70	56	42	
25	5/12/97	10		365						6	
26	2/1/98	6		1000	28					0	

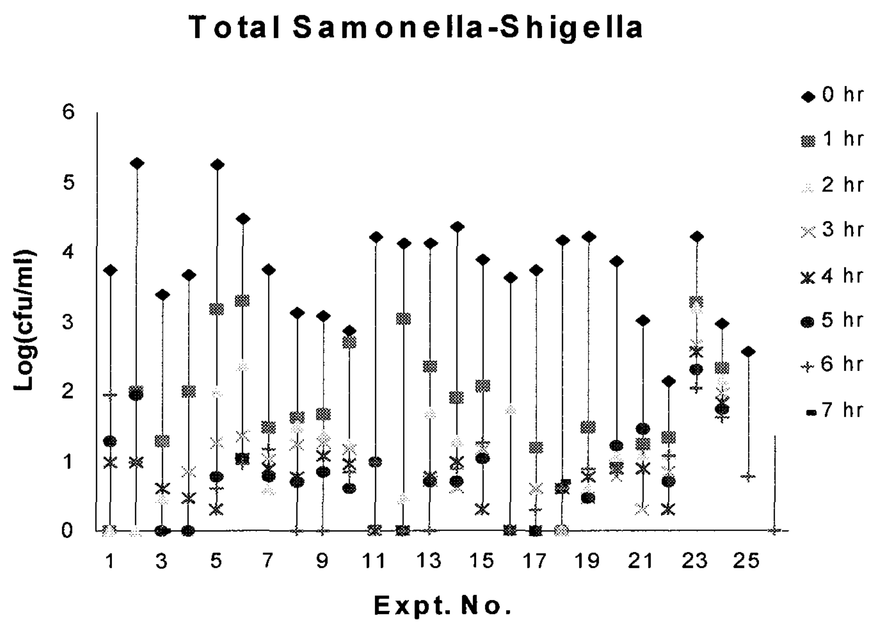

FIG. 5. Analyses of irradiated raw sludge-total Salmonella-Shigella.

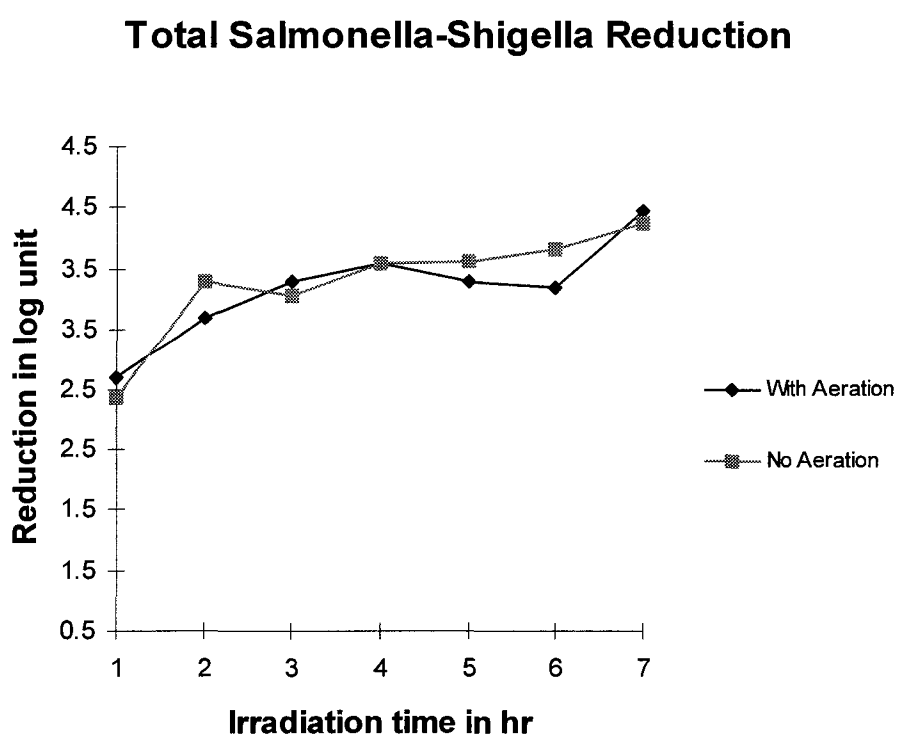

FIG. 6. Effect of aeration – total Salmonella-Shigella.

9. REGROWTH STUDIES

Regrowth of Total Coliforms were observed after 7–8 hours of treatment in the liquid sludge samples irradiated in this irradiator. As drying in the sand bed may take more than 7–8 hours, this may cause problems of recontamination with pathogenic bacteria.

Hence, this aspect was taken up for study in detail. Efforts were directed to investigate the possibility of inadequate treatment due to geometric configuration of the radioactive sources, irradiator vessel dimensions and shape, piping system and liquid sludge flow. Radiotracer study of SHRI irradiator and study of dose distribution by TL dosimetry technique are carried out.

Post irradiation inoculation with some agriculturally useful bacteria were carried out at BARC. The bacteria used for inoculation were phosphate solubilizer Enterobacter esburae and symbiotic nitrogen fixer Rhizobium leguminosarum. Both showed good growth in radiation sterilized sewage sludge. Their ability to grow in the presence of residual microflora is under investigation.

In another set of experiments, reduced volume of sludge 400 litres) was irradiated in the SHRI irradiator. It was felt that at present low source activity and large sludge volume dose rate are very low. It may result in recontamination of sludge during irradiation. As the other configuration of the irradiator could not be modified, volume of the batch was reduced. The experiments show improved results in terms of regrowth. They would be continued for further confirmation.

In an investigation by an external laboratory at Baroda, it was opined after confirmatory tests of about 8 samples of irradiated sludge, that the regrowth bacteria are not all coliform and/or salmonella-shigella. But these tests have to be further confirmed. Materials and methods adopted were as follows.

TESTS FOR THE CONFIRMATION OF COLIFORMS, SHIGELLA/SALMONELLA

Medium	Positive reaction	Possible interference
MacConkey Agar	+ ve (Pink colonies)	Coliforms
	– ve (Colourless colonies)	Salmonella /Shigella
EMB Agar	Metallic sheen	E. coli
Catalase test	+ ve (effervescence)	E.coli / Salmonella
	– ve (No effervescence)	Shigella

- EMB-Eosin Methylene Blue Agar for confirmation of Escherichia coli
- Catalase and Triple Sugar Iron Agar are for determining presence of E. Coli, Shigella and Salmonella group of organisms.

TRIPLE SUGAR IRON AGAR TEST

Reaction	Name of organism		
Colour change	Sh. Flexneri	Sh. Sonnei	Sh. Dysentriae
Slant	Acid	Acid	Acid
Butt	Alkaline	Acid	Acid
H_2S & Gas	+ ve / – ve	– ve / – ve	– ve / – ve
Colour change	S. typhi	S. Paratyphi A	S. Paratyphi B
Slant	Alkaline	Acidic	Alkaline
Butt	Acidic	Acidic	Alkaline
H_2S & Gas	– ve / – ve	– ve / + ve	+ ve / + ve

10. RADIOTRACER STUDY OF SHRI IRRADIATOR

Bromine-82 as aqueous ammonium bromide solution was used as a radiotracer to study the flow characteristics in the irradiator. The direction of sludge flow was varied from its designed direction of downward flow in irradiator. Study for once through instead of closed-loop recirculation was also carried out. Data on dead volumes, mixing time and residence time were generated. These parameters can be used to optimize the plant operation.

11. DOSE DISTRIBUTION BY TL DOSIMETRY

Experiments were carried out for examining the inadequacy of treatment in terms of uniformity of absorbed dose using dosimetry technique. As mentioned in the earlier CRP report, Thermoluminescence properties of sand give very good estimation of absorbed dose in the liquid sludge. Batch of sludge was irradiated in the irradiator for four hours. Twenty-eight samples (15 litres each) of sludge were collected after irradiation. Sand was separated from these samples for measurement of their TL. Five readings were recorded for each sample.

From a total of 145 sample readings, maximum value of TL (in arbitrary units per mass) of 10.00 and minimum value of 7.02 were recorded. The mean value of 8.66 with standard deviation of .55 were worked out.

Frequency distribution curve for the samples is plotted against normal distribution for comparison in Fig. 7.

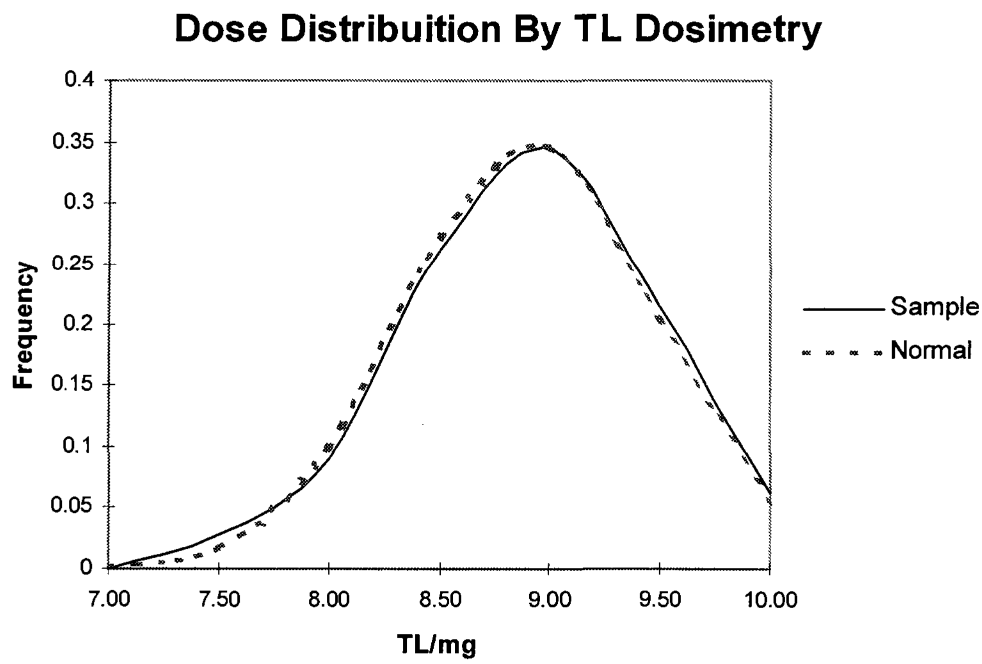

FIG. 7. Distribution of dose in SHRI irradiator.

TABLE V. DOSE DISTRIBUTION BY TL DOSIMETRY

Sample No.	TL (Arbitrary Unit) per mg Readings				
	1	2	3	4	5
1	9.79	9.32	8.89	8.51	8.85
2	9.43	8.49	9.02	8.43	9.06
3	8.18	7.92	8.44	7.45	8.60
4	8.55	8.89	9.18	8.30	9.02
5	8.73	8.80	8.36	9.06	8.33
6	9.17	9.36	10.00	9.78	8.72
7	8.52	9.02	9.57	9.35	9.18
8	9.06	8.97	8.21	8.16	8.25
9	8.57	8.24	8.21	8.57	8.44
10	8.93	9.07	8.91	8.25	8.45
11	10.00	9.27	9.47	9.51	9.06
11a	9.30	9.07	8.81	9.25	9.00
12	7.91	8.25	9.09	8.60	8.75
13	7.88	9.05	8.05	8.41	8.33
14	7.92	8.75	8.63	8.26	8.18
15	8.26	9.00	8.72	8.70	8.84
16	8.60	8.75	8.60	8.75	8.81
17	9.76	8.50	9.15	8.37	9.41
18	8.18	8.60	8.52	8.44	9.00
19	8.60	8.62	8.96	9.07	8.67
20	8.72	8.65	8.81	8.67	9.52
21	8.51	8.44	9.50	9.15	8.91
22	9.07	7.84	9.07	8.22	8.00
23	8.29	7.91	7.67	8.18	7.08
24	7.36	7.91	8.13	8.22	7.95
25	8.78	8.18	7.92	7.02	7.83
26	8.51	9.11	8.84	8.57	8.89
27	8.57	8.22	9.27	8.75	9.79
28	8.18	7.62	8.33	8.37	8.22

12. CONCLUSIONS

(1) A dose of about 2 kGy is found to be adequate for hygienizing the raw sewage sludge. Total Coliforms and salmonella-shigella counts are reduced below 100 cfu/ml. The dose of 2.7 kGy was observed for similar disinfection for digested sludge in earlier studies at SHRI Facility [7]. Average log unit reduction in Total Coliforms, Total Bacteria and Total Salmonella-Shigella in raw sludge was 3.6, 1.9 and 3.5, respectively, after four hour radiation treatment (absorbed dose 2 kGy) along with aeration.

(2) The variations in initial counts of bacteria are attributed to variations in the solid contents of the sludge. The functioning of primary settling tank of the conventional sewage treatment plant affects the raw sludge characteristics. Seasonal and climatic conditions affect the operation of the conventional treatment plant. But, the radiation hygienization are less affected due to these reasons. The reduced final counts(<100 cfu/ml coliform) are achieved irrespective of the initial counts (generally less than 10^6 cfu/ml of Total Coliforms) after 2 kGy dose.

(3) Aeration does not seem to reduce dose requirement significantly as observed in the case of digested sludge. However, average log unit reduction in case of Total Coliforms and Total Salmonella-Shigella was more in combination treatment than that in radiation treatment without aeration. Besides, aeration seems to reduce bad odour from the sludge under processing as well as from treated sludge.

(4) A few chemical analyses have shown reduction in BOD, COD, volatile solid, ammonia content and sulphide.

(5) Sand separated from the sludge was used as an in situ dosimeter by making use of its thermoluminescence property. Average dose for two hours of irradiation was estimated to be 0.993 ± 0.03 kGy. This value of dose rate (i.e. 0.5 kGy/h) was considered for dose estimation.

(6) Dose distribution study with the help of measurement of TL of sand obtained from sludge has shown that the uniform dose was received by the sludge on recirculation for four hours. Mean value of TL was 8.66 with standard deviation of .55 for 145 observations.

(7) As the irradiator is operating at low source strength, microbiological investigations for reduced volume irradiation treatment are carried out. There is improvement in the results in respect of regrowth of bacteria.

13. PROPOSED STUDIES

— Further investigation on regrowth of bacteria is very essential. Experiments using reduced volumes of sludge will be carried out.

— The irradiated sludge can be mixed with some natural chemicals having antibacterial and antifungal activity. They will be selected in view of economic viability.

— Centrifugal decantation of sludge will dry the sludge in very short period of time. Sludge dried with this method can be studied for its regrowth potential.

— Toxic chemical and odour removal will be studied in detail.

— Treatment after replenishment of radioactive sources are planned to observe the effect of increased dose rate. Also, it is planned to reduce the irradiator vessel volume.

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