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ORIGINAL CONTRIBUTION

Qualitative and Quantitative Assessment of Sewage Sludge by Gamma Irradiation with Pasteurization as a Tool for Hygienization

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Abstract In this research work, management of sewage sludge disposal on agricultural soils is addressed. The increasing amount of sewage sludge and more legislative regulation of its disposal have stimulated the need for developing new technologies to recycle sewage sludge efficiently. The research was structured along two main avenues, namely, the efficacy of the irradiation process for removing enteric pathogenic microorganisms and the potential of irradiated sludge as a soil amendment. This study investigated how application of irradiation with heat treatment reduced pathogens in sewage sludge. Raw and pasteurised Sewage sludge was treated at different dose treatment of 1.5, 3 and 5 kilogray (kGy) gamma irradiation individually and for 3 kGy sufficiency was achieved. Decrease in irradiation dose from 5 to 3 kGy was observed for pasteurised sludge resulting in saving of radiation energy. The presence of heavy metals in untreated sewage sludge has raised concerns, which decreases after irradiation.

Keywords Disinfection · Sewage sludge · Pathogens · Hygienization · Pasteurization · Irradiation

Introduction

With increase in human population and rapid urbanization along with industrialization, there is a progressive problem of disposal of increasing sewage sludge. Indiscriminate discharging, dumping, burning and burying of these wastes have led to unacceptable levels of atmospheric pollution. Unfortunately, most sewage treatment plants receive industrial toxic wastes, which contain some potentially harmful components including heavy metals such as chromium, lead and mercury which are then mixed with the human wastes, creating a pernicious mixture of nutrients. Albeit high in initial cost, the radiation route is simple, compact, and efficient. Radiation treatment has no adverse effect on the nutritional values of the sludge. Therefore, land application of radiation disinfected sludge, to return its organics and nutrition back to the soil is perhaps the most desirable sludge management strategy. However, the direct use of sewage sludge has a few environmental and public health concerns because of the presence of heavy metals, pathogenic bacteria, and other toxic substances that may limit its application as soil fertilizer [1]. Effective hygienization of sewage sludge by gamma radiation is well documented [2]. In India, only 30 % of the sewage sludge is being treated before its discharge [3]. Total sewage generation from urban regions in India is about 30 billion L a day, while the total sludge treatment capacity is estimated to be only 3 billion L a day [3].

Gamma irradiation is effective for wastewater treatment, not only for the elimination of total bacterial flora, faecal coliforms, total coliforms, and reduction of BOD and COD, which improves the quality of wastewater, but also in keeping the nutrients elements (NPK) for use as a natural fertilizer [4]. Gamma irradiation has been recognized as a new method to eliminate pathogens in sewage sludge [5]. In the opinion of radiation scientists, 3–5 kGy of gamma radiation is adequate to completely inactivate pathogens in sewage sludge. The researchers have reported a dose of 3 kGy for sludge decontamination [6] and found that 5 kGy is the appropriate disinfection dose for dewatered sludge [7], whereas it has been found that a dose of 1 and

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6 kGy are sufficient for disinfection of sewage water and sewage sludge respectively [8]. In the opinion of radiation scientists, 3–5 kGy of ionizing radiation is adequate to completely inactivate pathogens in sewage sludge.

Materials and Methods

Sewage Sludge Analysis

The moist sewage sludge (semi-solid) used in this study was collected from inlet of the sewage treatment plant, Situated 15 km away from the main city of Kolkata. It treats wastewater accumulated from different sources, around 80–85 % of the sewage biosolids were from different industrial and household origin and the rest from other sources like hospitals, railway station etc. The sewage sludge sample was screened through 0.5 mm mesh in order to get rid of large objects such as branches, sand plastic bags. The thickened sewage sludge sample was sun dried on an open drying bed which was covered for overnight to avoid the unnecessary moisture absorption by drizzle or dew. It was kept under the sun for 1 week. The atmospheric temperature averaged about 27 °C, with the initial moisture of about 85–95 %.The sample was removed from the open sun after a week and weighed, it was noticed that 10–15 % of moisture loss has been observed, revealing that the dried sludge was not completely dried retaining 65–75 % of moisture. The sun dried sludge was distributed into 500 ml rigid borosil beakers and carried to CGCRI, Kolkata for irradiation treatment of sewage sludge cautiously shaken uniformly and vigorously before dosing.

Technical Specifications

The isotopes which are traditionally used as a commercial source of gamma radiation were cobalt-60. Manufacture of the gamma irradiation facility located at CGCRI is BRIT, Navi, Mumbai and the model name is GC 5000. It has 44 radiation source pencils and an irradiation volume of 5,000 cm^3

Dosimetry Details and Chemical Analysis

The sludge samples were irradiated with a dose rate of 1.5–5 kGy in sealed glass bottles with a working volume of 500 mL at ambient temperature (around 25C). Raw sample was irradiated at 1.5, 3 and 5 kGy. Similarly, it was repeated for pasteurized sewage sludge. The 0 kGy sample was kept as a control sample for pasteurized sewage sludge as well as raw sludge sample. These samples were subsequently taken to the laboratory for the chemical analysis and determination of the required physicochemical properties. The pH and other physico-chemical properties of sewage sludge were determined using standard analytical methods [9]. The digested solution was analyzed for phosphorus (P) by Olsen's method, potassium (K) by spectrophotometer.

Results and Discussions

The effect of gamma rays on the decomposition of organic materials in the sewage sludge was evaluated as a function of absorbed dose by determining the change of BOD, COD, total coliform, fecal coliform, organic carbon, phosphorus, sulphate, nitrate, potassium, chromium, copper, lead, iron.

The radiation treatment effectively lowered BOD (Fig. 1). The reduction observed was around 93 % for non pasteurized sewage sludge even at low irradiation of 1.5 kGy and the reduction of around 99 % at 3 kGy for pasteurized sewage sludge and 73 % for pasteurized sludge treated at the dose of 5 kGy. This indicates the

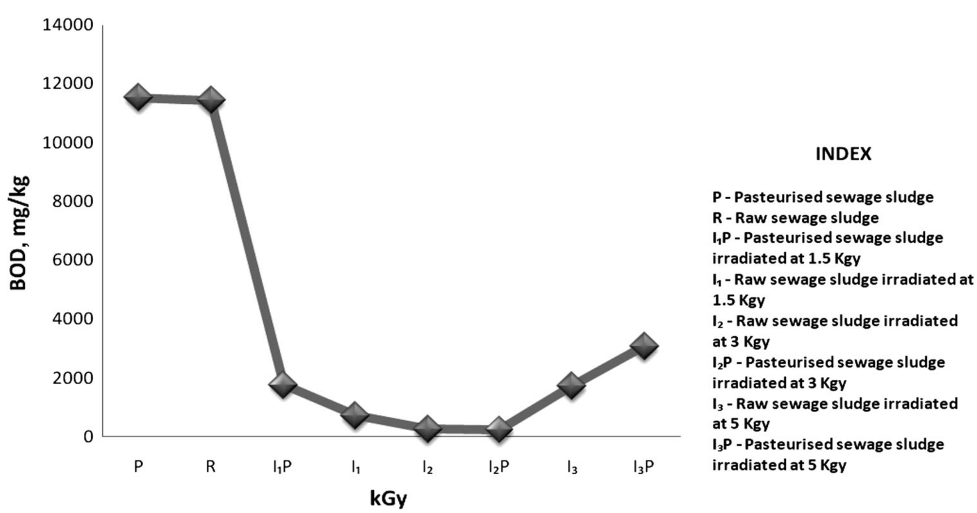

Fig. 1 Effect of irradiation on BOD of sewage sludge

Table 1 Physicochemical characteristics of raw, irradiated and pasteurized, pasteurized sewage sludge treated at different irradiation doses

Parameters	R	P	I_1P	I_1	I_2	I_2P	I_3	I_3P
pH	6.2	7.2	6.4	6.48	6.6	6.8	6.85	6.92
BOD, mg/kg	11,442	11,524	1,763	706	241	223	1,715	3,065
COD, mg/kg	1,763	71,549	11,443	5,307	2,434	2,481	7,790	29,424
Organic Carbon, mg/kg	29,732	26,898	4,106.70	3,852	915	803.1	2928.40	11,061
Phosphorus, mg/kg	32.89	118.39	118.30	58.70	38.30	36.90	80	282.30
Sulphate, mg/kg	12.5	654.40	674.90	282.80	115.70	115.70	538.20	652.30
Nitrate, mg/kg	0.62	261.90	42	16.40	7.90	8.02	26.40	99.80
Nitrogen, mg/kg	0.62	3,004.10	399	198.60	101.60	100.80	311.50	1,087.90
Potassium, mg/kg	16.2	110.6	49.40	39.60	17.30	17.10	29.80	101.70
Chromium, mg/kg	0.925	9.280	1.065	0.795	17.30	0.584	0.820	4.0670
Zinc, mg/kg	19.28	119.22	58.8	62.5	78.8	80.5	83	111.11
Copper, mg/kg	21.2	15.38	14.89	13.9	9.1	11.8	10.92	13.89
Lead, mg/kg	7.92	18.63	5.42	1.17	1.44	1.721	3.753	7.65
Iron, mg/kg	6.4	3,921.70	630.20	280	263	340.12	347.5	389.9
Total coliform, MPN/g	11×10^7	79×10^6	31×10^6	21×10^6	14×10^6	12×10^6	26×10^6	46×10^6
Fecal coliform, MPN/g	4.8×10^7	23×10^6	6.8×10^6	4×10^6	2×10^6	1.8×10^6	6×10^6	13×10^6

biodegradable organic materials can be easily decomposed even at a low absorbed dose.

Irradiation was having direct effect on sulphate (Table 1). The maximum sufficiency was achieved for pasteurized sludge. Increase of irradiation dose resulted in the decrease of sulphate concentration of the sewage sludge. Concentrations of heavy metals like chromium were highest in pasteurized sludge (Table 1). The maximum removal efficiency was achieved for raw sewage sludge irradiated at 3 kGy i.e. 39 %. But for pasteurized sewage sludge slight increase was noticed and removal efficiency of 36 % was achieved. The soil accumulations of heavy metals from sludge will not cause environmental or health hazard [5].

The pH of the sewage sludge after pasteurization and irradiation at different doses is shown in Table 1. The pH in raw sludge was 6.2 and increased to 7.71 when pasteurized sludge treated with the dose of 5 kGy. The pH obtained after irradiation dose treatment doesn't show much variation and the peak was obtained for pasteurized sewage sludge irradiated at 5 kGy. Decrease in soil pH and bulk density was reported by several investigators [10]. Significant removal of lead was observed for raw sludge irradiated at 1.5 kGy (Table 1). The difference in removal efficiency of Lead was around 32 % insignificant for sludge irradiated at 1.5 and 3 kGy. [11] Also revealed that the concentrations of Zn, Cu and Pb were lower than the National Standard limit.

Figure 2 shows the removal efficiency achieved for BOD and COD. The removal percentage of BOD of sludge sample was increased from 7 to 14.5 for the dose of 1.5–3 kGy. The highest removal efficiency for BOD obtained is 98.05 % for pasteurized sludge treated with dose of 3 kGy. The efficiency of sewage sludge treatment wastewater plants and kinetics characteristics of biological processes are usually studied through BOD and COD [12]. Similarly, the removal percentage of COD of sludge sample was increased from 7 to 12.5 for the dose of 1.5–3 kGy. In an average removal efficiency achieved for BOD was greater than COD.

The maximum difference of total coliform with raw sludge was observed for pasteurized sludge irradiated at 3 kGy which shows the total coliform decreases by 2 log cycle (Fig. 3). The removal of toxic elements and pathogens that may affect human health needed to be considered [13]. Removal of fecal coliform by 2 log cycle was observed (Fig. 4). Results obtained from the present study at a dose rate of 3 kGy for pasteurized sludge were shown

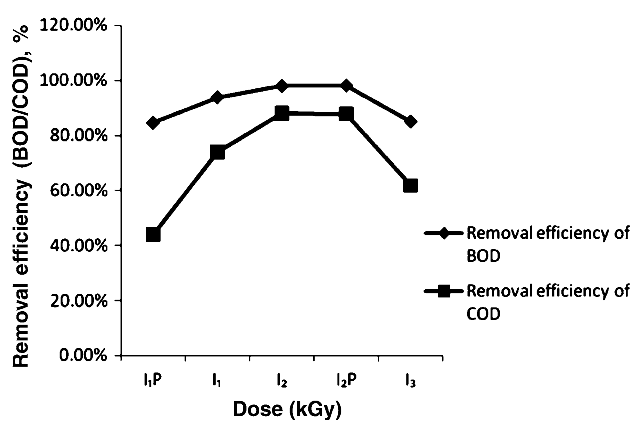

Fig. 2 The change of removal efficiency of BOD & COD after irradiation and pasteurization

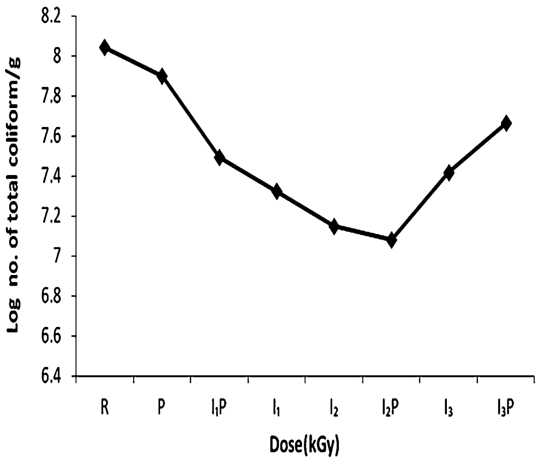

Fig. 3 Effect of irradiation on total coliform of sewage sludge

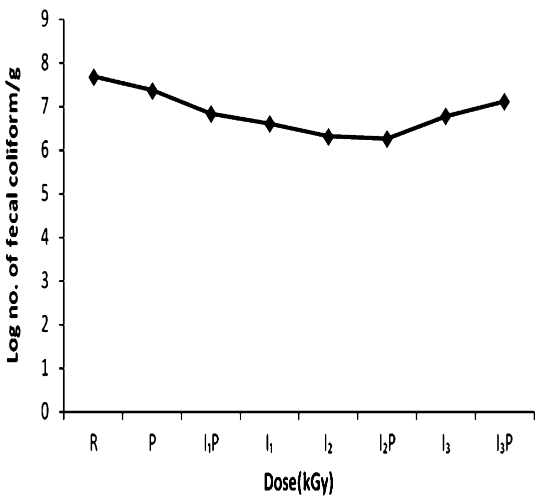

Fig. 4 Disinfection of fecal coliform by gamma rays as a function of irradiation dose

to be more efficient for the disinfection of sewage sludge. Radiation treatment using gamma-rays or electron beams is a simple and efficient technique that can remove a wide variety of organic contaminants and disinfect harmful microorganisms as well [14]. This study concludes that both total and fecal coliforms were reduced to below detection limit.

Figure 5 shows the inactivation of total and fecal coliform at 3 kGy. Regrowth of microorganisms was not detected. The fecal and total coliform appeared to be very sensitive to radiation with high removal percentage of around 97 and 98 respectively achieved for pasteurized sludge irradiated at 3 kGy. This excellent disinfection compared with other processes may be due to the high redox potential of the reactive radicals such as the hydroxyl radicals produced during gamma irradiation [15]. Doses between 1.5–5 kGy reduced 2 log cycles of the most probable number for total coliforms. It was concluded that

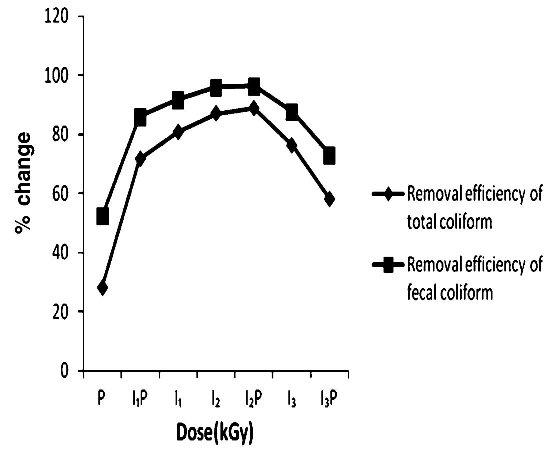

Fig. 5 The change of removal efficiency of total coliform and fecal coliform

treatment with gamma radiation was efficient in the elimination of coliform bacteria and prevention of regrowth [16]. At the dose treatment of 1.5 kGy, 16 % reduction in total organic carbon was noticed for pasteurized sludge which is less appreciable then sample given dose treatment of 3 kGy (Table 1). 95 % of reduction in total organic carbon was observed after irradiation. Good sufficiency of organic carbon was achieved for pasteurized sludge irradiated at 3 kGy.

Table 1 shows that sludge with relatively high rates of irradiation may increase NO^{-3} in the soil; which is due to nitrification in comparison with similar rates of non-irradiated sludge. In contrast, it was observed that release of NH^{4+} causes a negative effect of irradiation on nitrogen availability [1]. Nitrogen shows very less slope as result of very less irradiation effect on its concentration, 85.35 % of increase in potassium concentration was observed for pasteurized sludge and 7.2 % of increase for pasteurized sludge irradiated at 1.5 kGy. Pasteurised sludge shows the maximum increase of 93 % for phosphorus concentrations and 81.82 % of increase was observed for the pasteurised sample irradiated at 5 kGy but 42 % of increase was observed when pasteurised sludge was irradiated at 3 kGy which is a good nutrient sufficiency for the crops [17]. For pasteurized sludge quiet a high amount of nitrogen was observed but it is beyond the tolerance limit (Fig. 6).

Highest macronutrient phosphorus was observed for pasteurized sewage sludge i.e. 282.30 mg kg^{-1} safe [17]. Irradiation results in increase in phosphorus, since radiation induces mineralization. Potassium concentration was abysmally low in irradiated sludge sample with respect to pasteurized sludge sample. It was reported that the concentration of K in plants receiving irradiated sludge were similar to those in plants with raw sewage sludge [18]. For pasteurized sludge, efficiency of 86 % was achieved which is within the tolerance limit [17].

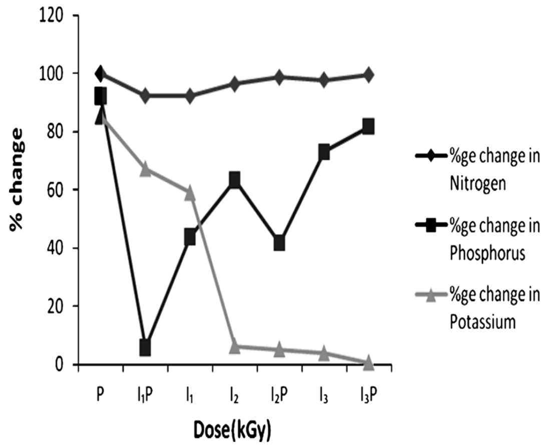

Fig. 6 Change in macronutrients after pasteurization and irradiation treatment

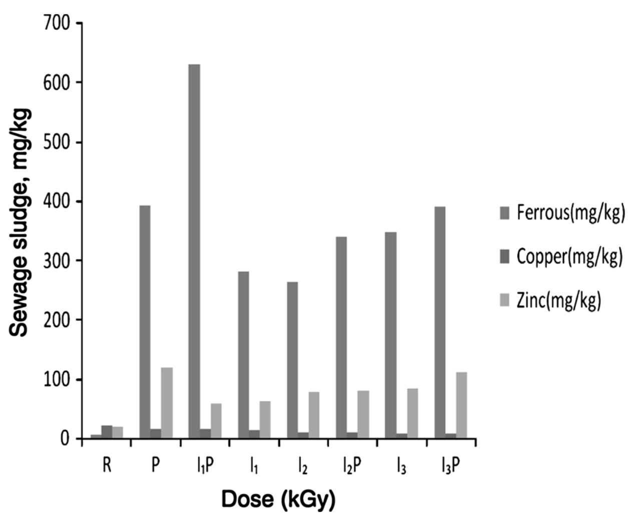

Fig. 7 Fe, Cu, Zn before and after irradiation and pasteurization of sewage sludge

Figure 7 shows the micronutrient concentrations in the sewage sludge as affected by irradiation at different doses. The toxicity level of Zinc (Zn) was 1,500 mg kg^{-1} [5]. The Zinc concentrations were within the range of sufficiency (26.8–98.5 mg kg^{-1}). Irradiation was having indirect effect on zinc concentration of sewage sludge. Sludge irradiated at 1.5 and 3 kGy also supplies a good amount of zinc required for the plant growth and also within the safe national standard limits. In contrast to this [18] observed no change in Zn concentration by sludge irradiation. Raw sludge gives the good sufficiency of copper to be used as fertilizer. In general, the concentrations of zinc, sulphate, copper decreases, probably due to dilution effect. Significant sufficiency of 630.20 mg kg^{-1} was achieved for pasteurized sewage sludge irradiated at 1.5 kGy [17]. Iron concentration was recorded to be highest followed by

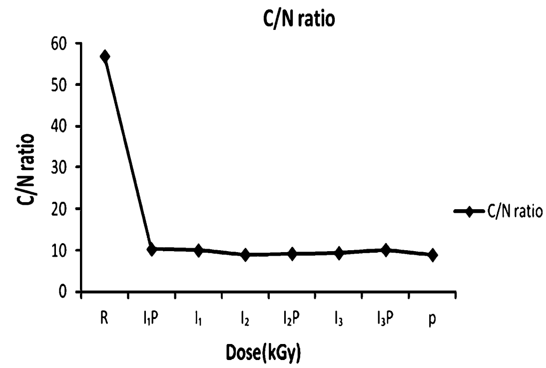

Fig. 8 Carbon: Nitrogen of the sewage sludge before and after irradiation at different doses

zinc.C/N ratio for raw sludge was 57 and almost similar ratio was observed for pasteurized sludge and irradiated sludge varying between 8–10 (Fig. 8). If the C:N ratio is too high (excess carbon), decomposition slows down and ends up with a stinky pile.

Conclusions

- The gamma irradiated sewage sludge was compared with conventional pasteurized sludge and raw sewage sludge in terms of its physico-chemical properties. No harmful effect of irradiation on sludge was noticed.
- The nutrient and heavy metal concentrations in irradiated sewage sludge also indicated no adverse effects. Some favorable effects were noticed in certain nutrient concentrations, i.e. Fe and P content. Increase in nitrogen was obtained but it was below the sufficiency level. It is concluded that sewage sludge disinfection dose is 3 kGy for pasteurized sludge for better pathogen free sludge and the reuse of irradiated sewage sludge is environmentally safe for recycling in agriculture.
- Based on the radio sensitivity of coliforms as a marker organism for disinfection, the adequate disinfection dose is 3 kGy with heat treatment. This implies that irradiation of pasteurized sewage sludge leads to saving of radiation energy as in the earlier research 5 kGy was recommended for complete inactivation of pathogens in sewage sludge.
- In this study, accumulation of heavy metals derived from sewage sludge in soil were found to be far lower than the maximum limit prescribed by the U.S.E.P.A and the EU.
- The separate and combined effects of heat and gamma radiation on sludge, for pathogen, micronutrients and macronutrients was studied and it was observed that combined effect of heat and radiation (thermo radiation) at 3 kGy results in inactivation of pathogens i.e. removal of 98 %.

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