Radiation Hygienisation of Municipal Sewage Sludge: A New Way of Urban Waste Management

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Abstract

Management of huge quantities of municipal sewage sludge generated in metropolitan cities is a big problem for urban development authorities. Appropriate treatment and disposal of sewage sludge is imperative to protect the environment, for health of the citizens, for aesthetics of the cities and for optimum use of land area. BARC has developed a technology for effective treatment of sewage sludge based on the fact that radiation can cause lethal damage to micro-organisms. The article briefly describes various activities carried out at BARC regarding the developed technology and the journey from liquid sludge hygienisation to dry sewage sludge hygienisation.

Keywords: *Radiation, hygienisation, sewage-sludge, pathogen, deactivation, soil-nutrient*

1. Introduction

Rampant urbanisation, exponential population growth and industrialization have caused enormous pollution load on environment. The most critical and voluminous source of water pollution is wastewater from human habitats categorized as black water and grey water. The prime component of black water is human faeces and urine while that of grey water is wastewater from kitchen washing, shower, laundering and other activities and mainly consists of human waste and exudates [1]. The centralised collection of wastewater is increasingly adopted by urban development agencies for it appropriate treatment. Treatment of wastewater in plants meant for treatment of sewage (STPs) leads to generation of sludge which because of its origin is categorized as sewage sludge. Organic material is major constituent (40-80%) of solid sludge as

its origin is human excreta which itself is a complex mixture of ingredients of human diet. Significant part of the organic material is a cocktail of living and non-living pathogenic and non-pathogenic microorganisms [2]. Disposal of sewage sludge is a huge challenge because of its volume as well as pathogenic load. The traditional methods of sewage sludge disposal with associated drawbacks are listed in Table 1.

The presence of various micro and macro nutrients along with organic matter in sewage sludge makes it inarguably a beneficial material of great potential for agricultural applications. Sewage sludge can be a valuable manure, provided it undergoes stabilization process for mitigating its pathogenic load. The sludge stabilization is generally achieved through processes in which the readily decomposable material is converted into colloidal, humified lignoprotenious material and human and animal pathogens are partially rendered ineffective.

Modern cultivation practices have caused deterioration of agricultural land through loss of organic matter, depletion of nutrients and soil erosion leading to significant decline in soil productivity. The productivity of deteriorated soil can be restored to acceptable level using various sources of organic wastes viz. sewage sludge, crop residues and animal manure [3].

Table 1: Sewage sludge disposal methods and associated drawbacks

Methods	Drawbacks
Incineration	Energy intensive, High cost
Disposal in the water bodies	Causes pollution of precious water source and adversely affects marine environment and hence whole food cycle
Landfill	Land becoming scarce especially around cities
Disposal on agricultural land	Desirable but can be a potential health hazard

Sewage sludge contains N, P, K and organic matter which makes it a potential resource for improvement of soil health acting as efficient manure and soil conditioner. Sewage sludge can be an excellent soil conditioner as the humic components of sludge provide suitable surrounding for growth of roots. Also the sludge humus provides conducive atmosphere for nutrients in sludge to be released in right combination and optimum rate for better plant growth. Microbes present in soil accelerate degradation of any biodegradable organics remaining in sludge. It is expected that use of sludge through land spreading would become more popular as soil becomes less nutritive and land is available at premium for land-fill particularly in and around cities. Thus, application of sewage sludge to farm land would be fair way to salvage soil health provided it is done in a way which does not harm surrounding atmosphere, health of animals and human beings around. The sludge after conventional treatment at STPs remains heavily loaded with pathogenic microorganisms and thus requires necessary treatment for pathogen de-activation before it is put for agricultural applications. Many countries have developed their own standards and guidelines for use of sewage sludge in agriculture considering E. Coli as an indicator bacteria for pathogenic load.

2. Radiolytic hygienisation of sewage sludge

The pathogenic load of sewage sludge restricts its reutilization, though it is good nourishment for farmland. Thus there is a need to include a step in treatment process to effectively de-activate the pathogenic organism with a high level of trustability to harness its beneficial nutrient properties.

The Cobalt-60 (Co-60), produced artificially in nuclear reactors has a half-life of 5.27 years and emits two gamma rays of energies 1.17 and 1.33 MeV. The high-energy gamma rays emitted

by Co-60 are energetic enough to inactivate pathogens with an elevated degree of dependability in a decent and coherent manner. The ionizing radiation interacts directly and indirectly with DNA and proteins (Figure 1) of micro-organisms causing cell death. Indirect interactions are caused due to radiolytic products of water. Radiolysis of water results in the formation of highly reactive oxidative (OH radical) and reducing species (H radical and aqueous electron) which efficiently interact with the DNA, to bring out changes which cause cell death.

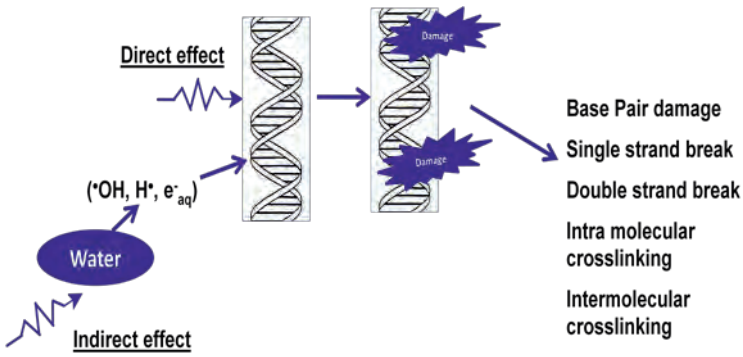

Figure 1: Direct and indirect affect of irradiation on DNA

Presence of oxygen enhances the radiation damage through formation of peroxides. Formation of peroxides causes permanent damage due to high stability of peroxide thereby causing irreparable damage. In fact, radiation damage to micro-organism is the cornerstone of radiation sterilization of medical products. The radiation treatment of sewage sludge offers a methodical, easy and dependable method to produce pathogen free sludge, which can be further upgraded to produce a value added bio-solid. Thus irradiation of sewage sludge as a tertiary treatment process provides a viable solution to the sewage sludge disposal and plays an important role in providing organic matter and micronutrients to the soil.

3. Sludge hygienisation research irradiator facility

Asia's first radiation treatment plant to hygienize municipal sewage sludge, Sludge Hygienisation Research Irradiator (SHRI), Vadodara, India was established by Bhabha Atomic

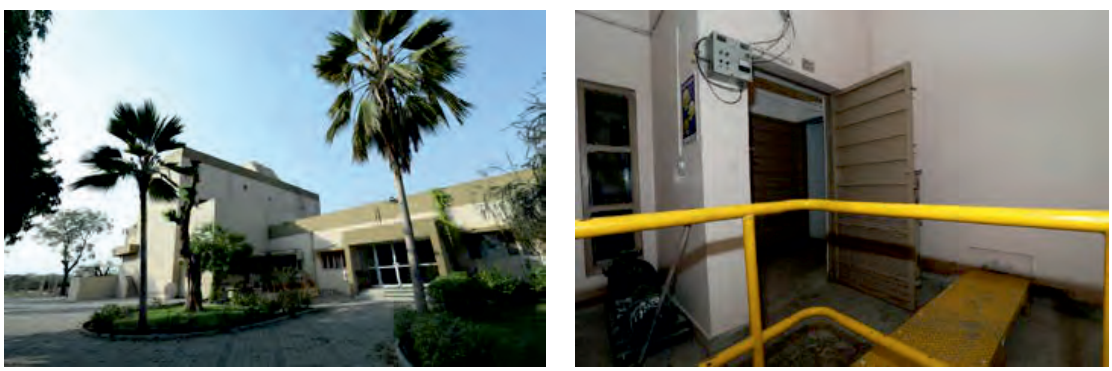

Figure 2: Photographs of exterior and interior of SHRI plant

Research Centre in collaboration with Vadodara Municipal Corporation and Government of Gujarat in 1992. It is an indigenously designed, technology scale demonstration plant with objectives to i) Set-up a foundation for radiation hygienisation of sewage sludge ii) Operate indigenously designed and install liquid sludge irradiator iii) Illustrate compatibility with traditional sewage treatment plants iv) Investigate suitability of employing municipal sewage sludge as manure & soil conditioner for farming v) Evaluate economic feasibility of the whole process [4]. The photograph of the plant is given in Fig. 2.

The SHRI plant consists mainly of three components namely (Figure 3)

- A Cobalt-60 gamma energy source contained in an irradiation vessel
- A shielded room for housing the irradiator
- A product handling system for sludge

The radiation hygienisation of liquid sewage sludge is simple process where only one parameter the absorbed dose is to be optimised and assured. The process involves feeding of incoming liquid sludge into irradiation vessel and running it uninterrupted in a closed loop for a pre-established period to deliver desired dose. After irradiation the liquid sludge is moved to sand beds where water seeps through and dry pathogen free sludge is obtained. Schematic of hygienisation procedure adopted at SHRI plant is shown in Fig. 3.

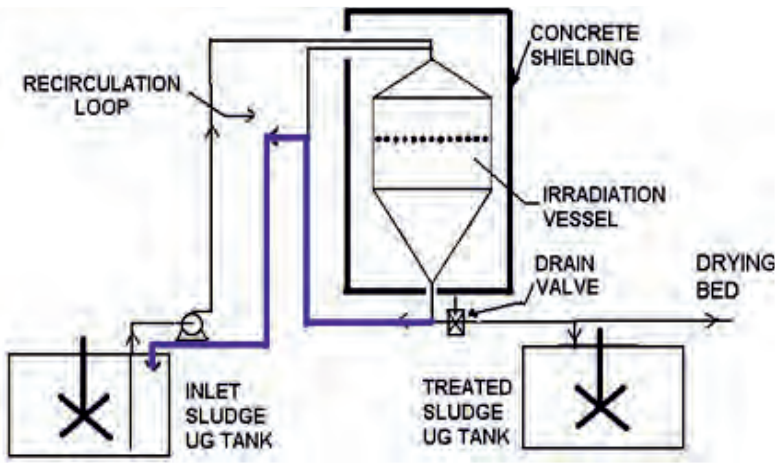

Figure 3: Sludge hygienisation process

The type of pathogenic species and their loading extent in sewage sludge can vary markedly depending upon time, site, local conditions and existing robustness of the population. Since it is practically not possible to monitor treated sludge for the presence of pathogens suitable surrogate organisms are monitored for routine evaluation of sludge quality. E. Coli found regularly in the sludge with similar defiance to radiation treatment as pathogens in sewage sludge is monitored at SHRI for radiation hygiensiation validation [5]. Survival curve of total coliforms present in sewage sludge as function of absorbed radiation dose is shown in Figure 4. The results indicate that an absorbed dose 3 kGy is sufficient to bring down the gross coliform counts by ~4 $\log_{10}$ cycles.

The two decades experience of running SHRI established that ~3kGy of absorbed dose assures deactivation of ~99.99% of pathogenic bacteria incessantly. The radiation processed

sludge is odourless and the radiation hygienisation plant can be smoothly unified with typical STPs with option of operation in combinatorial or standalone mode even by non-radiation workers.

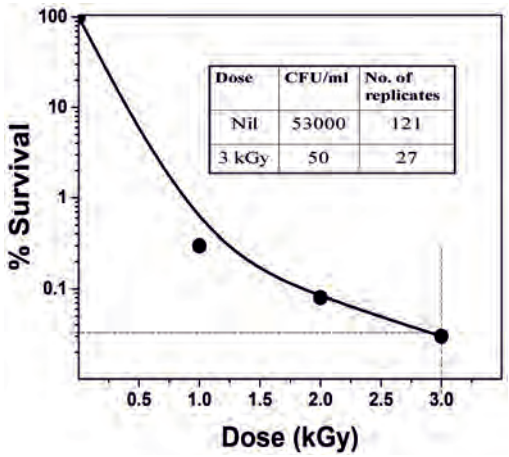

Figure 4: Survival of coliform microbial population with absorbed dose

Extensive field trials for making use of radiation processed municipal sewage sludge in the agricultural farms carried-out by BARC in collaboration with Krishi Vigyan Kendra (KVK), Vadodara have shown that the hygienized sludge is effective not only in improving crop yields but also the soil treated with the sludge maintains the soil moisture content for longer durations [6]. The hygienised sludge can be effective medium for growing other agriculturally important bacteria like Rhizobium which can further add to soil health and improve crop yield [7]. More than 5000 tons of sludge hygienised at SHRI facility has been used in different areas of Gujarat

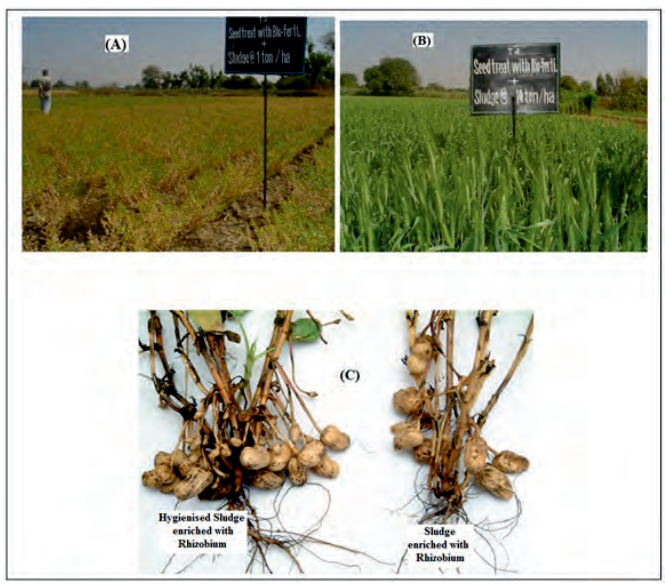

Figure 5: Photographs of (A) & (B) Large scale field trials of hygienised sludge (C) Effect of rhizobium enriched hygenised and non-hygienised sludge on groundnut growth

for large scale agricultural field trials in various crops in various seasons under a tripartite MoU between BARC, Krishi Vigyan Kendra (KVK), Vadodara and M/s Jupiter Agri-Inputs Corporation (JAIC), Vadodara. Figure 5 shows some pictures of field trials of hygienised sewage sludge.

4. Hygienisation of dry municipal sewage sludge

Radiation hygienisation experience gained from SHRI facility, Vadodara and studies carried out on various agricultural crops using hygienised sludge established that not only it improves the production yield but also improves the soil health in long run as the use of chemical fertilisers in farmlands can be reduced significantly. However SHRI employed liquid sludge irradiation process (85-90% water and 10-15% solids) thus the throughputs were low. In order to improve upon the throughputs to improve upon the economics and efficacy of sludge hygienisation process hygienisation of dry sludge, produced at sewage treatment plants (STP) was carried out. Here In addition to the radiation hygienisation of the sewage sludge, a consortium of beneficial bacteria (Bio-NPK) is added to it to make it enriched organic manure [8]. An average dose of 10 kGy recommended for Class-A category of bio-solid by United States Environmental Protection Agency (USEPA) is delivered to sludge and hygienised sludge is sprayed with optimised amount of Bio-NPK. Based on this technology, the first technology demonstration plant of capacity ~100 tons/day has been designed, constructed and commissioned under MOU between Ahmedabad Municipal Corporation (AMC), Bhabha Atomic Research centre (BARC) and Anand Agricultural University (AAU) at Ahmedabad, Gujarat. With the initial ^{60}Co source strength of 150 kCi, the facility is operational since January 2019. Figure 6 provides schematic of gamma radiation hygienisation process of dry sludge.

More than 350 tons of sludge has been hygienised at AMC plant and has been used for in-house application like 'Mission Million Trees' project of Ahmedabad Municipal Corporation, which targets carpeting all barren land in Ahmedabad city to dense greenery. In addition, the

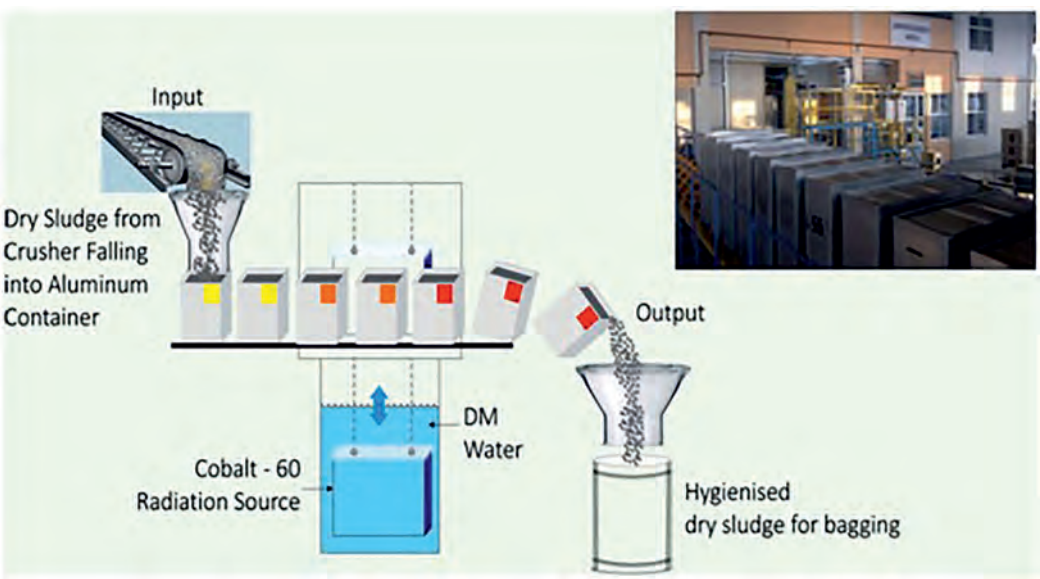

Figure 6: Schematic showing radiation hygienisation dry sewage sludge

radiation hygienised sewage sludge is also being used for horticulture applications by AMC. AMC has also conducted field trials of the radiation hygienized sewage sludge samples on different crops, in collaboration with Anand Agricultural University and results reported indicate that the chemical fertilizer load can be significantly reduced using hygienised sludge. Figure 7 shows some photographs of the AMC plant. After successful setting up and operation of the AMC plant, second plant is under construction at Indore under a MoU between BARC and IMC (Indore Municipal Corporation) and another MoU has been signed within Pune Municipal Corporation for establishing similar plant at Pune.

Figure 7: Radiation hygienization plant at Ahmedabad (A) Outside view of the plant (B) Inside view of the plant (C) Processed sludge bags

5. Conclusions

The current practice of disposing sewage sludge for agriculture applications carries the risk of infecting users because of its pathogenic load. The agriculture sector accounts for 18 per cent of India's gross domestic product (GDP) and it provides employment to 50% of the countries workforce. Thus the footprint of the pathogen related ailment including diagnostic cost, medication cost and loss of productivity can be a big drag to the development of country. The radiation hygienisation is a simple, economic, effective, reproducible and scalable process for treating sewage sludge to class-A biosolid. Utilization of hygiensied sludge in farm lands provides an economic and healthy way to increase production yield and improve soil health as well as provides urban development agencies room for effective management of sewage sludge.

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