A Study on India's Most Sustainable Method for Human Waste Management by Indian Railways-Part 2

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Abstract

Indian Railways' adoption of bio-toilets represents a l and mark in sustainable public infrastructure. By biologically decomposing human waste into treated water and biogas, bio-toilets prevent pollution, reduce track corrosion, conserve water and eliminate manual scavenging, thereby aligning with Sustainable Development Goals (SDGs) 3, 6 and 10. The system has proven to be scalable across ICF, LHB and Vande Bharat coaches and supports India's commitment to Swachh Bharat and environmental justice.

To complement the technical findings, this study incorporated an interactive discussion with a retired railway technician who worked extensively on the undergear of multiple coach types. His testimony revealed that the shift from open-discharge toilets to bio-toilets drastically improved workplace hygiene, reduced mechanical damage to undergear systems and created a cleaner and more dignified environment in pit lines. He also highlighted practical challenges, including the need for regular maintenance and the ongoing problem of passenger misuse, which can lead to system choking.

This paper builds upon earlier work presented at the ISURE 2025 International Conference (Part 1), which focused primarily on the technical evaluation, environmental benefits and water quality analysis of the bio-digester system. In this extended Part 2, we broaden the analysis by integrating field-level employee insights to demonstrate that bio-digester toilets are not only an eco-friendly innovation but also a social reform that improves the dignity, safety and working conditions of railway employees. Together, Parts 1 and 2 present a comprehensive view of how bio-toilets in Indian Railways serve as both a technological and social milestone in sustainable transit sanitation.

Keywords: Indian Railways, Bio-digester Toilets, Sustainable Development, Human Waste Management, SDG, DRDO, Undergear Pit Lines ,Sick lines .

1. Introduction

In 1909, a Bengali civil servant named Okhil Ch andra Sen wrote what would become one of the most iconic complaint letters in Indian history. Addressed to the railway authorities, his letter humorously described how the lack of toilets on Indian trains led to a personal mishap after consuming jackfruit. Though comical in tone, the letter revealed a deeply serious issue — the absence of basic sanitation facilities on public transport. The letter is now displayed at the National Rail Museum in New Delhi, serving as a reminder of how a single voice can highlight systemic neglect in public infrastructure.

For much of its operational history, Indian Railways, one of the world's largest and most widely used public transportation networks, relied on open-discharge toilets. These systems allowed human waste to be dropped directly onto the railway tracks, leading to severe environmental contamination, track corrosion and public health hazards. At stations and in densely populated areas, the consequences were especially dire — foul odours, water pollution, vector-borne diseases and unsafe working conditions for railway cleaning staff and manual scavengers.

With the rise of Swachh Bharat Abhiyan (Clean India Mission), India committed to transforming its sanitation standards across both rural and urban settings. Indian Railways, as a high-impact public service, became a key focus area. To align with national cleanliness initiatives and international sustainability commitments, especially the United Nations Sustainable Development Goals (SDGs) — including SDG 3: Good Health and Well-being, SDG 6: Clean Water and Sanitation and SDG 10: Reduced Inequalities — the railway ministry initiated a technological overhaul of its sanitation systems.

This paper investigates the transition from traditional open-discharge systems to eco-friendly anaerobic bio-digester toilets, designed in collaboration with the Defence Research and Development Organisation (DRDO). These toilets represent a significant step toward eliminating manual scavenging, reducing environmental harm and promoting social equity by ensuring hygienic conditions for all passengers, including those from marginalized and rural communities. The paper further examines how these systems function, their sustainability and their alignment with India's goals for inclusive, safe and green transportation infrastructure. This study employs a qualitative and analytical research methodology, grounded in a thorough review of technical documentation, field-level implementation data and case studies, with a focus on the environment-friendly sanitation systems used in Indian Railways. The primary source for technical insights is the Environment-Friendly Toilets (EFT) presentation developed by IIT Kanpur in collaboration with DRDO, which outlines the engineering, operational and environmental considerations behind the adoption of anaerobic bio-digester toilets in railway coaches.

Data Sources

Primary Sources: The official EFT presentation shared across railway training institutes. Field implementation reports from the Multi-Disciplinary Divisional Training Institute (MDDTI), South Western Railway, Bangalore. Technical notes and specifications from DRDO on inoculum composition and tank design. Secondary Sources: Published research papers, government reports and news articles related to Indian Railways' sanitation programs. Policy documents on SDGs and Swachh Bharat Abhiyan (Clean India Mission).Ministry of Railways guidelines and project outcome summaries.

Research Approach: A comparative evaluation method is used to study the evolution of toilet technologies within Indian Railways. Each system—open discharge, vacuum toilets, chemical toilets and bio-digesters—is evaluated using a sustainability framework that examines: Environmental impact (track cleanliness, water usage, pollution),Public health outcomes (hygiene, disease prevention),Operational feasibility (installation, maintenance, logistics),Social equity (accessibility, dignity, elimination of manual scavenging)

United Nations SDGs (2024) The United Nations Sustainable Development Goals (SDGs) emphasize inclusive sanitation (SDG 6), reduced inequalities (SDG 10) and climate action (SDG 13). Access to safe and sustainable sanitation is a human right and a foundation for social equity. The global agenda encourages innovations like bio-toilets that reduce open defecation, conserve water and improve public health outcomes, especially in developing nations (UN, 2024).

CAG Report on Bio-Toilets in Indian Railways (2017) A performance audit by the Comptroller and Auditor General of India (CAG) evaluated the large-scale induction of bio-toilets in passenger coaches. While appreciating the eco-friendly intent, the report identified maintenance gaps, faulty installations and the need for enhanced passenger awareness. Despite these issues, the initiative was deemed a critical step toward sustainable sanitation in rail transport (CAG, 2017).

Press Information Bureau – Status of Bio-Toilets (2019) According to the Ministry of Railways, more than 2.25 lakh bio-toilets had been installed in train coaches by 2019, aiming for complete coverage. The system replaced direct discharge with an eco-friendly alternative that aligns with environmental norms and prevents rail track corrosion. The statement reaffirmed the government's goal to make Indian Railways a zero-discharge network (PIB, 2019).

Indian Railway Question Bank on Bio-Toilets (2020) A technical overview explains how DRDO-developed bio-digester technology uses anaerobic bacteria (inoculum) to degrade human waste into methane and water. The inoculum remains effective in a wide temperature range, making it suitable for India’s diverse climatic conditions. The design requires no external power, enhancing sustainability and ease of deployment (Indian Railway Question Bank, 2020).

Medium Article – “The Green Revolution on Rails” (2023) This article highlights Indian Railways' bio-toilet initiative as a transformational step toward a green future. It discusses the role of DRDO’s bio-digester technology in reducing water usage, eliminating manual scavenging and aligning rail transport with national sustainability goals. Public-private collaboration and awareness campaigns are cited as key drivers of success (Northern Railways, 2023).

Analytical Tools: Descriptive analysis is used to interpret qualitative data, supported by: Tabulated comparisons of toilet technologies based on key performance indicators. Thematic analysis to identify patterns and recurring challenges in implementation. Case observation summaries (e.g., challenges reported by maintenance staff and field engineers).

4. Scope and Limitations: The study is limited to the Indian Railways context and primarily focuses on coach-mounted sanitation systems, excluding static toilet systems at stations. While the findings are based on credible sources, actual field performance may vary depending on region-specific infrastructure, staff training and passenger behaviour. Quantitative field data (e.g., bacterial survival rates, biogas output) are referenced from secondary technical reports but not independently measured.

5. Evolution of Toilet Technologies in Indian Railways: Indian Railways, serving over 23 million passengers daily, has historically faced immense challenges in maintaining hygiene and sanitation across its vast rail network. Until recently, sanitation infrastructure on trains remained archaic, relying on century-old technologies that posed serious risks to both public health and the environment. This section explores the evolution of toilet technologies adopted by Indian Railways, highlighting the shift from open-discharge toilets to more advanced and sustainable systems like bio-digester toilets. Each phase of development reflects changing priorities in terms of cleanliness, maintenance feasibility, ecological impact and social responsibility.

5.Discharge Toilets: For much of its existence, Indian Railways relied on gravity-based open-discharge systems. These toilets, essentially stainless-steel pans with direct discharge to tracks, allowed human waste to be released onto railway lines. While simple in design and cheap to maintain, these systems caused: Severe environmental pollution of tracks, soil and water bodies. Corrosion of railway infrastructure, increasing maintenance costs. Unhygienic conditions at stations, especially where trains were parked for long durations. Dehumanizing work conditions for manual scavengers who had to clean the tracks. The continued use of this system well into the 21st century signalled the urgent need for innovation in railway sanitation.

6. Controlled Discharge Toilet Systems (CDTS): As an interim solution, Controlled Discharge Toilet Systems were introduced. These systems stored human waste in tanks and released it only when the train was moving at a specified distance from stations, typically in rural or non-sensitive areas. While CDTS reduced pollution in populated zones, they still released untreated waste, posing environmental risks. Moreover, the electronics and pneumatics involved made them expensive and difficult to maintain. Without effective microbial treatment, these systems were not aligned with sustainability standards.

7. Chemical and Macerator Toilets: Another alternative explored was chemical toilets, where waste was mixed with disinfectants like formaldehyde or phenyl to control odour and bacteria. In some cases, macerator toilets were used to grind waste before storage.

These systems proved unreliable in Indian conditions, primarily due to: High chemical costs and the toxicity of disinfectants. Health hazards for workers handling chemical tanks Frequent clogging and component failure, especially due to plastic and solid waste Passenger misuse, like disposing of bottles and wrapper Although more advanced than CDTS, these systems were not practical or sustainable for widespread deployment.

7. Vacuum Toilets: Inspired by aerospace and aviation designs, vacuum toilets use suction to flush waste with minimal water. These were introduced in select luxury trains like Tejas Express.

Advantages: Low water usage (~500 ml per flush), Odourless and hygienic experience .Limitations :High capital and maintenance costs, Dependence on compressed air systems, which are not uniformly available across all coaches, Complex infrastructure requirements, making them unsuitable for retrofitting older train. Despite their technical promise, vacuum toilets remain limited to premium categories due to feasibility and scalability issues.

8. Zero Discharge Toilet: As environmental consciousness grew, zero discharge toilets were tested. These systems aimed to separate solids and liquids for onboard composting and evaporation, producing no effluent discharge. Challenges: Odor management issues Need for manual sludge handling. Space and design constraints Unreliable composting performance under variable train temperatures and usage pattern. While theoretically sound, the operational reality of Indian Railways made it difficult to implement zero discharge systems on a large scale.

9. The Rise of Bio-Digester Toilets: In response to these limitations, DRDO-designed anaerobic bio-digester toilets emerged as the most practical and scalable solution. These systems represent a paradigm shift — not only removing waste from public view but transforming it biologically into harmless byproducts. Their deployment in over 70,000 coaches marks the most significant sanitary transformation in the history of Indian Railways. The system: Reduces pollution, by treating waste inside the tank, Eliminates manual scavenging ,Reduces maintenance frequency, compared to CDTS or vacuum systems ,Aligns with the SDGs and Swachh Bharat Mission

The next section delves into the working principles, technical composition and real-world performance of these bio-digester toilets.

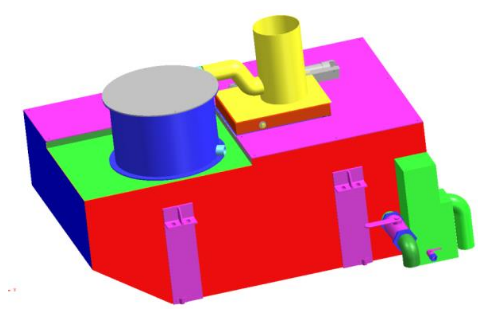
10. Anaerobic Bio-Digester Toilets: In response to the pressing need for a sustainable and scalable sanitation solution, the Defence Research and Development Organisation (DRDO) developed the anaerobic bio-digester toilet system, originally intended for military use in high-altitude, low-oxygen environments. Indian Railways adapted and scaled this technology to serve as a long-term solution to its sanitation crisis.

How It Works: The bio-digester toilet comprises a stainless-steel tank installed beneath the railway coach. Human waste from the toilet is routed into this tank, which contains multiple chambers filled with biofilm matrices colonized by anaerobic bacteria (referred to as inoculum). These bacteria decompose the organic matter in the absence of oxygen, converting it into: Biogas (primarily methane and CO_2), which is safely vented out. Treated water, which passes through a chlorination unit before being discharged onto the tracks. This entire process occurs within the tank, unlike previous systems that discharged untreated waste. The tank design includes flapper valves or S-traps to prevent backflow and odour.

Img: Bio toilet str Fixed in ICF Coach

Technical Components :Tank Capacity: Ranges from 300–600 liters depending on coach type Inoculum: Specially cultured from psychrophilic bacteria for longevity and resilience.

Mats/Grids: Increase surface area for bacterial colonization. Chlorine Dosing Unit: Treats the effluent before release .Variants: Bolted, welded and modular tanks suitable for different terrains



Img:3D Str of BIO Toilet attachment

11. Benefits of the System: The bio-digester toilet system offers multifaceted advantages, making it the most promising sanitation model currently in use by Indian Railways. These benefits are technical, environmental, economic and social in nature.

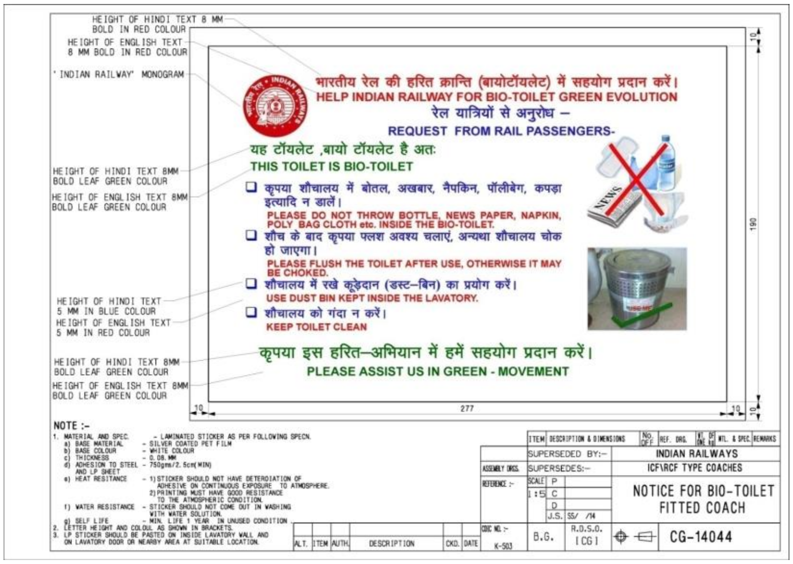
11.1Environmental Benefits: Zero Discharge of Untreated Waste: Unlike open-discharge or CDTS systems, bio-digesters contain and treat waste onboard. Reduction in Track Corrosion: Clean discharge leads to longer track life and reduced maintenance. No Chemical Usage: The system avoids harmful chemical disinfectants, protecting surrounding ecosystems.

12.1Public Health Benefits: Hygienic Coaches and Platforms: Cleaner surroundings help reduce disease transmission. Lower Disease Risk: Reduced exposure to pathogens from waste helps curb gastrointestinal and vector-borne diseases. Cleaner Water Sources: Prevents waste runoff into nearby rivers, ponds, or agricultural l and.

13.1Operational Benefits: Low Water Requirement: Typically 1–2 liters per flush, far less than conventional toilets. Minimal Sludge: Most solid waste is broken down biologically, reducing the need for frequent manual cleaning. Durability: Properly maintained tanks last for several years without needing replacement.

14. Social and Economic Impact: Eliminates Manual Scavenging: One of the most significant social benefits in terms of dignity and labour safety. Supports Swachh Bharat Abhiyan: Aligns with national goals for cleanliness and health. Scalable: Can be deployed in remote areas and retrofitted into old coaches. Cost-Effective in the Long Term: Although initial investment is high, reduced maintenance and cleaning costs balance it over time. Limitations and Challenges:Despite its many benefits, the bio-digester toilet system faces practical implementation challenges that must be addressed for optimal functionality.

13. Passenger Misuse: One of the most persistent problems is inappropriate disposal of non-biodegradable items such as: Sanitary pads, Plastic bottles and wrappers, Cloth, glass and metal items These can choke the inlet pipe or mats inside the digester, leading to clogging and reduced bacterial activity.



img: Information Stickers placed in toilet permisis

14.Maintenance Complexity: Skilled workforce is required to maintain the system, monitor chlorine dosing and clear obstructions.. Lack of routine inspection can lead to bacterial die-off, especially if chemical cleaners are mistakenly used in train toilets.

15.Inoculum Sensitivity: The bacterial culture is vulnerable to certain chemicals (e.g., phenyl, acid cleaners), which can drastically reduce its ability to digest waste. Re-inoculation is required in some cases, which increases cost and time.

16.Infrastructure Dependencies: Pit-line facilities are required to perform proper inspection and cleaning, which may not be available at all stations, especially in rural areas. Some legacy coaches may not be compatible with new tank dimensions or fittings.

17.User Awareness: Many passengers are unaware of how to properly use the toilet, leading to behaviour that damages the system. Lack of signboards or public announcements results in misuse, especially on long-distance trains Addressing these challenges requires a combination of technological upgrades, passenger education and policy-level interventions to ensure the long-term success of the bio-digester system.

18. Contribution to SDGs and Environmental Justice: The implementation of anaerobic bio-digester toilets in Indian Railways contributes directly and significantly to multiple Sustainable Development Goals (SDGs), reinforcing India's commitment to global sustainability targets while addressing deeply rooted issues of social inequality, public health and ecological degradation. Alignment with

18.1 SDG 3 – Good Health and Well-being. The proper management of human waste helps prevent the spread of infectious diseases such as cholera, typhoid and hepatitis. By eliminating open defecation and reducing human exposure to raw sewage, the bio-digester system plays a pivotal role in improving the health of passengers and workers alike.

18.2 SDG 6: Clean Water and Sanitation: Bio-digesters help reduce contamination of surface and groundwater by ensuring that untreated human waste is not discharged onto railway tracks or into nearby water bodies. The chlorinated effluent is safe and meets key environmental parameters, making it a responsible sanitation method in terms of water quality and reuse potential.

18.3 SDG 10 Reduced Inequalities: Historically, sanitation-related tasks have disproportionately fallen upon marginalized communities, especially manual scavengers. The bio-digester system removes the need for such undignified labour, helping promote equity and human rights. It ensures access to clean sanitation for all passengers, regardless of class, caste, or income.

19:Environmental Justice: Environmental justice refers to the fair treatment and meaningful involvement of all people in environmental policies. By adopting eco-friendly sanitation solutions: Indian Railways reduces pollution in vulnerable communities near tracks. Wastewater discharge is minimized in rural and tribal areas, which are most affected by environmental degradation. Sanitation access becomes more inclusive, respecting human dignity and reducing health disparities. Through bio-digester toilets, Indian Railways not only enhances sustainability but ensures that environmental benefits are equitably distributed.

2.Objectives of this study

1.To examine the structure, working mechanism and technical components of anaerobic bio-digester toilets,

2.To test the quality of water -Physical factors and Biological factors by MPN Test

3.To isolate the microorganism by spread plate method and identify the microorganisms

3. Methodology

Effluent Quality: The treated water is evaluated physical and biological methods

1.**Prepare the Test Tubes**

Composition of broth

Component	**Quantity (g/L)**	**Purpose**
Lactose	5.0 g	Fermentable sugar to detect gas production
Peptone	5.0 g	Nitrogen source for bacterial growth
Beef Extract (or Yeast Extract)	3.0 g	Provides vitamins, minerals & additional nutrients
Sodium Chloride (NaCl)	5.0 g	Maintains osmotic balance
Distilled Water	1000 ml	Solvent
pH	Adjusted to 6.8 ± 0.2	Optimal for bacterial growth

1. Take **three sets of test tubes** (usually 3 tubes per set), each filled with a suitable amount of **Lactose Broth**.

2.Inoculate the Tubes with Sample

-In the **first set**, add **0.1 ml** of the sample.

-In the **second set**, add **1 ml** of the sample.

-In the **third set**, add **10 ml** of the sample.

3.Ensure Sterility

All inoculations are done using **sterile pipettes or droppers** to prevent contamination.

4.Add Durham Tubes

Place **inverted Durham tubes** inside each test tube to collect gas, which may be produced during microbial activity.

5.Incubate the Tubes

Incubate all the tubes at **37°C for 24–48 hours**.

6.Observe for Positive Reaction

After incubation, check each tube for **turbidity, colour change, or gas formation** — signs of microbial presence.

7.Record the Results

Note the **number of positive tubes** in each dilution group (e.g., 3 positive at 10 ml, 2 at 1 ml, 1 at 0.1 ml).

MPN Broth Result Day 1:- No air bubble

4.Result

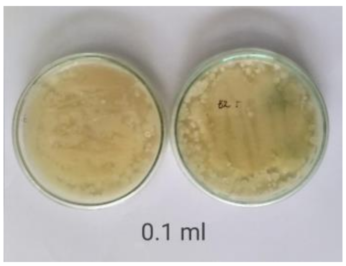
MPN Broth Result Day 2:- Air bubble formation showing Presence of microorganism

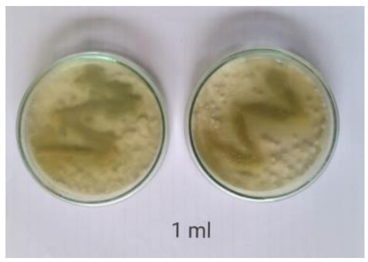
:- 4-3-2 (10 ml: 4 positive, 1 ml: 3 positive, 0.1 ml: 2 positive

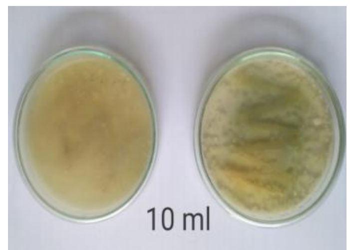
:-Change in colour of broth due to white precipitate

Post inoculation

MPN culture media after inoclated with the microbial air bubble derived from broth







Physical description for 100 ml of solution

Turbitity :Present

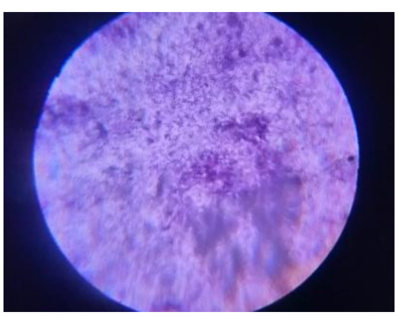
Smell : Foul odour present without chlorination

Colour :Pre filtration - brown (filterable components)

:Post filtration - clear no turibity

pH :10 - Strong base

Gram staining : Gram + ve



9.Discussion

The transition to bio-digester toilets is a l and mark innovation in public sanitation, especially given the scale and diversity of Indian Railways. Compared to earlier systems open discharge, chemical and vacuum toilets—bio-digesters offer a more sustainable balance between technological feasibility, environmental protection and social responsibility. Comparative Advantage: Bio-digester toilets outperform others in terms of: Environmental compliance (zero untreated discharge)Low water usage (1–2 liters per flush vs. 10–15 liters in conventional toilets).Ease of retrofitting in older coaches. Social impact (removal of manual scavenging and inclusive access).Practical Insights from Implementation Field observations and railway staff interviews reveal that while the system is technically sound, real-world implementation requires: Continuous training for cleaning and maintenance staff. Public awareness campaigns to prevent toilet misuse. Better monitoring mechanisms at pit-lines to check effluent quality A reserve supply of inoculum for re-inoculation in high-usage or chemically affected tanks Opportunities for Innovation: Looking forward, Indian Railways could explore: Hybrid solutions that combine vacuum systems with bio-digester treatment. Use of smart sensors to detect clogging or bacterial performance in real time. Research into high-efficiency bacterial strains for faster waste breakdown. Effluent reuse for non-potable purposes, such as cleaning or irrigation in station yard. Thus, while the foundational model is sound, continued policy support, technological refinement and public participation are key to maximizing the impact of these toilets.

10.Interaction for Information

The following content is a transcribed version of an audio-recorded conversation. As the respondent did not wish to reveal his identity, we have respected his request. Presented below is the plain transcript of the discussion between the research team and the respondent.

To complement the technical and environmental evaluation of bio-digester toilets, this study incorporated an interactive discussion with a retired railway technician who had extensive experience working on the undergear of ICF, LHB and Vande Bharat coaches.

His insights provide valuable first-h and knowledge of the practical challenges faced by employees before and after the adoption of bio-toilets in Indian Railways.

The technician explained that prior to the introduction of bio-toilets, the open-discharge system created an extremely unhygienic and unsafe work environment. Human waste fell directly onto the tracks, often splashing onto the undergear of coaches. This not only generated foul odour and an unpleasant atmosphere but also damaged mechanical components, increasing maintenance difficulties and costs. Employees were compelled to work in unhealthy conditions, particularly during undergear inspections and repairs at pit lines.

He recalled that bio-toilets began to be introduced in Indian Railways between 2010 and 2015, initially fitted only in ICF coaches. With subsequent technological adaptations, the system was expanded to LHB coaches and is now standard even in advanced trains such as Vande Bharat. The shift to bio-toilets significantly improved the cleanliness of pit lines and reduced exposure to waste for employees, creating a safer and more dignified workplace.

However, the technician also highlighted operational considerations. Bio-toilets perform effectively when properly maintained, requiring regular refilling of chlorine tablets, inoculum reinforcement and vacuum pumping of tanks. The major challenge arises from passenger misuse — such as disposing of bottles, wrappers, or sanitary products in the toilets — which leads to clogging and obstructs the digestion process. While vacuum toilets were also tested, he noted that they are comparatively more delicate and less suited to Indian passenger behavior, making the bio-toilet a more practical and sustainable option.

Overall, the interaction confirmed that the introduction of bio-toilets has not only addressed environmental and technical concerns but also transformed the working conditions of railway employees, reinforcing the link between sustainability, occupational safety and social justice.

11. Conclusion

The introduction of anaerobic bio-digester toilets by Indian Railways marks a revolution in railway sanitation infrastructure, replacing antiquated systems with a solution that is sustainable, inclusive and ecologically sound. From its early reliance on open-discharge systems—infamous for polluting tracks, corroding infrastructure and endangering health—Indian Railways has transformed itself into a global model for green public transportation.

Through this study, we have shown that the bio-digester system not only treats human waste safely but also addresses multiple layers of sustainability: **Environmental**, by preventing pollution and preserving natural resources; **Economic**, through cost savings on maintenance and infrastructure; **Social**, by promoting dignity and eliminating manual scavenging; and **Technical**, through a scalable model adaptable across diverse railway zones. The system's alignment with SDGs 3, 6 and 10 further illustrates its value in India's broader developmental goals.

The interactive discussion with a retired railway technician further reinforced these findings by providing lived evidence from the field. His experiences revealed how bio-toilets significantly improved the cleanliness of pit lines, reduced damage to mechanical undergear and created a safer, more dignified working environment for employees. This perspective highlights that the technology's success lies not only in its environmental benefits but also in its ability to transform the everyday realities of railway workers.

However, no technology is without its limitations. Misuse by passengers, maintenance challenges and bacterial sensitivity continue to pose hurdles. Overcoming these requires collective efforts from policymakers, engineers, passengers and sanitation staff.

In conclusion, Indian Railways' bio-digester toilets are not just a technological fix—they represent environmental justice, workplace dignity, public health reform and national progress. With continued innovation, proper maintenance and community engagement, this model can serve not only India but the world as a blueprint for sustainable and socially equitable transit sanitation.

12.Reference

1. United Nations. (n.d.). *Sustainable Development Goals*. Retrieved from https://www.un.org/sustainabledevelopment/

2. United Nations Department of Economic and Social Affairs. (n.d.). *The 17 Goals*. Retrieved from https://sdgs.un.org/goals

3. Comptroller and Auditor General of India. (2017). *Performance Audit on Induction of Bio-Toilets in Passenger Coaches in Indian Railways (Report No. 36 of 2017)*. Retrieved from https://cag.gov.in/uploads/download_audit_report/2017/Report_No.36_of_2017_-_Performance_Audit_on_Induction_of_bio-toilets_in_passenger_coaches_in_Indian_Railways_Union_Government.pdf

4. Press Information Bureau. (2019, July 4). *Indian Railways committed to provide Bio-Toilets in all its coaches*. Retrieved from https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1607379

5. Indian Railway Question Bank. (2020, January). *Railway Questions Bank: C&W Bio-Toilet*. Retrieved from https://indianrailwayquestionbank.blogspot.com/2020/01/railway-questions-bank-c-w-bio-toilet.html

6. ScienceDirect. (n.d.). *Most Probable Number (MPN)*. Retrieved from https://www.sciencedirect.com/topics/pharmacology-toxicology- and-pharmaceutical-science/most-probable-number#:~:text=The%20most%20probable%20number%20(MPN)%20is%20a%20statistical%20method%20used,is%20%3C%2010%2C000%20cells%20per%20gram.

7. Press Information Bureau. (2022, January 31). *Indian Railways achieves 100% electrification on broad gauge routes of some zones*. Retrieved from https://pib.gov.in/Pressreleaseshare.aspx?PRID=1809572

8. Press Information Bureau. (2016, December 2). *Availability of Bio-Toilets in Indian Railways*. Retrieved from https://pib.gov.in/newsite/PrintRelease.aspx?relid=154824#:~:text=At%20present%2C%20there%20are%20more,2%20December%202016%20(Friday)

9. Department of Science & Technology (India). (n.d.). *Self-propelled railway track scavenging vehicle can replace manual scavenging*. Retrieved from https://dst.gov.in/self-propelled-railway-track-scavenging-vehicle-can-replace-manual-scavenging#:~:text=Despite%20the%20ban%20on%20manual,with%20high%2Dpressure%20water%20jets.

10. Business St andard. (2022, March 16). *No manual scavenger working for Indian Railways: Ashwini Vaishnaw*. Retrieved from https://www.business-standard.com/article/current-affairs/no-manual-scavenger-working-for-indian-railways-ashwini-vaishnaw-122031601332_1.html

11. Indian Railways Institute of Mechanical and Electrical Engineering. (n.d.). *Project on Bio-Toilet*. Retrieved from https://rskr.irimee.in/sites/default/files/PROJECT%20BIO%20TOILET.pdf

12. Northern Railways. (2021). *The Green Revolution on Rails: Bio-Toilets in Indian Railways*. Retrieved from https://medium.com/@NorthernRailways/the-green-revolution-on-rails-bio-toilets-in-indian-railways-1d7541697901#:~:text=In%20response%20to%20this%20problem,sustainable%20era%20in%20rail%20travel.