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Development of Self-Deodorizing Drainage Infrastructure Using Intelligent Microbial Consortia Embedded in Smart Biocarriers

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Abstract

Urban wastewater management faces persistent issues with odor emissions, impacting public health and environmental quality. This study explores the development and application of self-deodorizing drainage infrastructure by integrating intelligent microbial consortia into smart biocarriers. Designed to biologically neutralize malodorous compounds such as hydrogen sulfide (H2S) and ammonia (NH3), this system leverages advancements in microbial biotechnology, environmental engineering, and materials science. The research was carried out in collaboration with CSIR-NEERI, Nagpur, and focuses on microbial consortia optimization, encapsulation in bio-compatible carriers, and field-scale implementation. Results demonstrate a significant reduction in odor intensity and improved biodegradation efficiency, suggesting strong potential for decentralized urban drainage solutions.

Keywords: Self-Deodorizing Infrastructure, Intelligent Microbial Consortia, Smart Biocarriers, Wastewater Odor Control, Environmental Biotechnology

1. Introduction

Drainage infrastructure in urban environments is often plagued by the emission of foul-smelling gases, which pose both aesthetic and health hazards. Traditional methods to control odour, such as chemical dosing or mechanical aeration, are often energy-intensive, costly, and environmentally taxing. Recent advancements in microbial biotechnology offer a promising alternative: the use of engineered microbial consortia capable of metabolizing odorous compounds. This paper presents a comprehensive study on the design, development, and field validation of a novel self-deodorizing drainage system. The system utilizes intelligent microbial consortia—engineered for enhanced metabolic pathways—embedded within smart biocarriers capable of sustained microbial release and environmental resilience.

2. Literature Review

Previous studies have reported the effectiveness of individual bacterial strains like Thiobacillus, Pseudomonas, and Bacillus subtilis in degrading H2S and NH3. However, their application in open drainage systems remains limited due to low retention time and environmental stressors. Microbial consortia provide synergistic advantages, and when combined with smart carriers, they demonstrate enhanced survival and functional efficacy.

3. Materials and Methods:

3.1 Development of Microbial Consortia:

A consortium was formulated using bacterial isolates from sewage-impacted environments. Genomic screening and metabolic profiling ensured the selection of strains with complementary functions. Strains were evaluated for H_2S and NH_3 degradation, biofilm formation, and resilience against pH and temperature variations.

3.2 Design of Smart Biocarriers:

Biocarriers were synthesized using biodegradable polymers like alginate and polyvinyl alcohol (PVA), supplemented with nano-silica for improved strength and porosity. Carriers were designed to offer slow release and physical protection to microbial colonies.

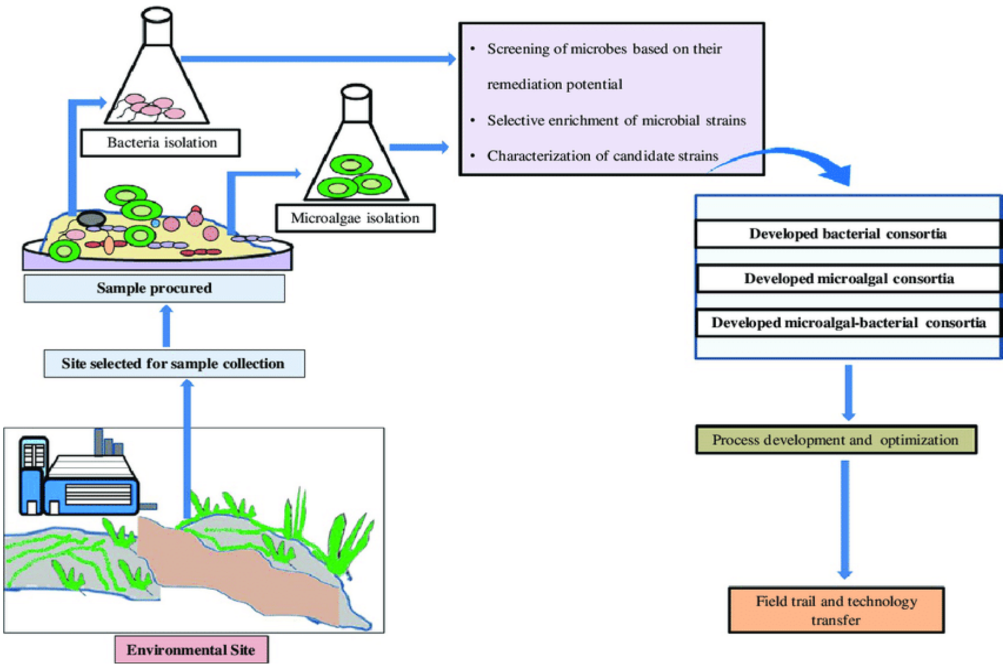
3.3 Embedding Protocol:

Immobilization of microbial consortia into carriers followed an encapsulation-dripping method under sterile conditions. Encapsulated carriers were incubated for 48 hours before field deployment.

3.4 Field Deployment and Monitoring:

Pilot implementation was carried out in a tertiary drainage line of Nagpur city under the guidance of CSIR-NEERI. Parameters monitored included:

- Odor Intensity Index (OII)
- Biochemical Oxygen Demand (BOD)
- Concentration of H2S and NH3
- Microbial viability



4. Results and Discussion

4.1 Microbial Efficacy The consortium demonstrated over 85% reduction in H2S and 78% in NH3 under controlled conditions. In field conditions, average odor intensity dropped by 65% within two weeks of deployment.

4.2 Biocarrier Performance Smart biocarriers maintained structural integrity for 21 days and supported sustained microbial activity. SEM imaging confirmed uniform microbial embedding.

4.3 Environmental Impact The system did not introduce any secondary pollutants and resulted in a 22% reduction in BOD levels, contributing positively to overall water quality.

Tabular Summary of Results

Parameter	Condition	Observed Result	Interpretation
H_2S Reduction	Controlled Environment	85% reduction	High microbial efficacy against sulfur compounds
NH_3 Reduction	Controlled Environment	78% reduction	Effective nitrogenous compound degradation
Odor Intensity Reduction	Field Conditions	65% reduction within 2 weeks	Demonstrates real-world efficacy and adaptability
Biocarrier Integrity	Immersion Duration	Maintained for 21 days	Robustness of smart biocarrier design
Microbial Embedding	SEM Imaging	Uniform microbial distribution	Ensures consistent biodegradation activity

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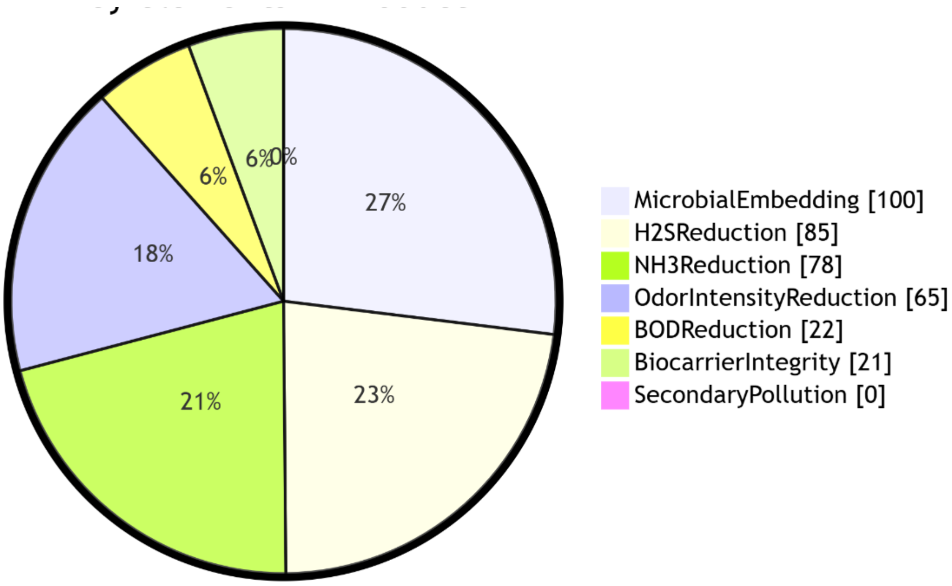
BOD Reduction	Effluent Post-Treatment	22% reduction	Improved water quality with reduced organic load
Secondary Pollution	Ecotoxicological Assessment	No harmful by-products or pollutants detected	Environmentally safe implementation



5. Applications and Future Scope:

The system is scalable and can be adapted for decentralized wastewater treatment, especially in slums and peri-urban settlements. Future research can explore automated replenishment systems and AI-based odor prediction models.

6. Conclusion:

This research confirms the viability of using intelligent microbial consortia embedded in smart biocarriers for odor control in urban drainage infrastructure. The system not only mitigates odors but also contributes to wastewater quality improvement in a sustainable and cost-effective manner.

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