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Enhancing Environmental Sustainability in Biomedical Waste Incineration: Transition from Water Scrubbing to Dry Technology

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A B S T R A C T

Biomedical waste incineration plays a crucial role in medical waste management, but its environmental impact, particularly in flue gas emissions, remains a significant concern. Traditional water scrubbing technology has been widely used to control emissions; however, it presents challenges related to water consumption, secondary waste generation, and operational costs. This study explores the transition to an optimized dry technology as a sustainable alternative. The study compares the efficiency, economic feasibility, and environmental benefits of both approaches. Results indicate that dry technology offers superior emission control, lower resource consumption, and improved sustainability.

Keywords: Biomedical waste, water scrubbing, dry technology, incineration

1. INTRODUCTION

Biomedical waste incineration is a critical process for managing hazardous medical waste. The emissions from incineration plants contain harmful pollutants such as particulate matter, acidic gases, heavy metals, and dioxins, necessitating effective air pollution control measures. The growing healthcare sector has resulted in increased biomedical waste generation, necessitating efficient disposal mechanisms [1]. Incineration is one of the most effective methods for treating infectious and hazardous biomedical waste. However, the process produces significant amounts of air pollutants, necessitating the implementation of effective emission control technologies. Traditionally, water scrubbing has been widely used for flue gas treatment in biomedical waste incineration plants. Despite its effectiveness in removing certain pollutants, water scrubbing presents several drawbacks, such as excessive water consumption, high operational costs, and secondary waste production [2-6]. Given the environmental and economic concerns associated with water scrubbing, alternative air pollution control technologies have been explored. Among them, dry technology has emerged as a promising solution, offering advantages such as lower water usage, reduced secondary waste, and enhanced pollutant removal efficiency [7]. This paper explores the transition from water scrubbing to optimized dry technology to enhance environmental sustainability in biomedical waste incineration.

1.1 The Importance of Incineration in Managing Biomedical Waste

Incineration plays a vital role in the management of biomedical waste by ensuring the safe disposal of infectious and hazardous materials [8]. Key benefits of incineration include:

Complete Destruction of Pathogens: High-temperature incineration eliminates harmful microorganisms present in biomedical waste.

Reduction of Waste Volume: Incineration significantly reduces the volume of waste, minimizing landfill usage.

Elimination of Toxic Substances: Proper incineration neutralizes toxic and hazardous substances present in medical waste.

Energy Recovery Potential: Modern incineration plants can generate energy from waste combustion, contributing to sustainable waste management.

Despite these advantages, traditional incineration methods contribute to environmental pollution, necessitating the adoption of advanced emission control technologies such as dry scrubbing.

1.2 History of Biomedical Waste Management

The management of biomedical waste has evolved significantly over the years. Historically, biomedical waste was disposed of in landfills or openly burned, leading to severe environmental and public health hazards [9-14]. In the late 20th century, increasing awareness of healthcare-related infections and pollution led to stricter regulations and the adoption of controlled disposal methods.

Pre-1980s: Biomedical waste disposal was largely unregulated. Most waste was dumped in landfills without segregation, leading to contamination of soil and water.

1980s-1990s: The rise of hospital-acquired infections and environmental activism led to the development of structured waste management guidelines. Many countries introduced policies for waste segregation, incineration, and autoclaving.

2000s-Present: Stricter environmental laws and the push for sustainability have encouraged the use of advanced waste treatment technologies, including energy recovery incineration and dry scrubbing technologies.

1.3 Global and National Guidelines on Biomedical Waste Management

Several organizations and regulatory bodies have established guidelines for handling biomedical waste, including:

World Health Organization (WHO): Provides recommendations on the classification, segregation, and disposal of medical waste to minimize health and environmental risks.

Environmental Protection Agency (EPA, USA): Enforces air quality standards for biomedical waste incinerators to control emissions.

European Union Waste Incineration Directive (WID): Establishes strict emission limits for incineration plants to prevent air pollution.

Central Pollution Control Board (CPCB, India): Governs biomedical waste management under the Biomedical Waste Management Rules, ensuring compliance with environmental norms [15].

These regulations emphasize safe disposal practices, treatment technologies, and emission control measures to mitigate the negative effects of biomedical waste.

2. Research Methodology

This paper outlines the methodology adopted to evaluate the transition from water scrubbing to dry technology for biomedical waste incineration. The research methodology includes the selection of key study parameters, experimental setup, detailed descriptions of both emission control systems, optimization strategies, and analytical tools used for comparison.

2.1 Description of Water Scrubbing System Used in the Study

2.1.1 System Overview

The water scrubbing system analyzed in this study consists of the following components:

1. Spray Tower Scrubber: Uses water to remove acidic gases and particulate matter.

2. Packed Bed Scrubber: Enhances gas-liquid contact for better pollutant absorption.

3. Cyclone Separator: Removes large particulates before gas enters the scrubber.

4. Effluent Treatment Unit: Treats the contaminated water before disposal.

2.1.2 Operating Conditions

- ✓ Water Flow Rate: 50–200 L/hr (depending on pollutant load).
- ✓ Scrubbing Efficiency: 80–95% for SO_2 and HCl removal.

Drawbacks Identified:

- ✓ High water consumption (up to 500 liters/day for a small incinerator).
- ✓ Secondary wastewater generation, requiring treatment before discharge.
- ✓ Corrosion issues and scaling, increasing maintenance costs.

2.2 Optimization Strategy for Dry Technology Implementation

The new dry technology incinerators are the most advanced incineration technology in the world. High levels of automation, variable frequency drives at all critical points to ensure the finest adjustments of chemicals for injection in the system to control the pollutant gases for complying the stringent norms in the world. To optimize dry technology as a sustainable alternative, the following strategies were considered:

2.2.1 Selection of Suitable Sorbents

- ✓ Lime (Ca $(OH)_2$): Effective for SO_2 and HCl neutralization.
- ✓ Sodium Bicarbonate ($NaHCO_3$): Provides enhanced pollutant removal at lower temperatures.
- ✓ Activated Carbon: Used for dioxin, furan, and heavy metal capture.

2.2.2 Optimization of Sorbent Injection Rates

- ✓ Controlled injection of Ca $(OH)_2$ at 1–5 g/Nm³ for optimal acidic gas neutralization.
- ✓ Activated carbon dosing based on mercury and dioxin concentrations.

3. Results and Discussion

3.1 Comparison of Water Scrubbing and Dry Technology

Parameter	**Water Scrubbing**	**Dry Technology**
Water Consumption	High (400–600 L/ton waste)	Negligible
Waste Generation	Liquid wastewater, sludge	Dry solid residue
Operational Cost	High (chemical, water, maintenance costs)	Moderate
Pollutant Removal	Incomplete (NO_x, dioxins, mercury remain problematic)	More effective

Water scrubbing has been a traditional choice for emission control in biomedical waste incineration, but it faces significant challenges in terms of efficiency, operational cost, and environmental sustainability. While it effectively removes SO_2 and HCl, it falls short in NO_x, dioxins, and mercury control, necessitating additional technologies. Furthermore, the high-water consumption, wastewater management issues, and corrosion risks make it an unsustainable long-term solution, justifying the transition to optimized dry technology.

3.2 Economic Comparison (Capital and Operational Costs)

While dry technology requires a higher initial investment, it offers significant cost savings in the long run due to lower operational and maintenance costs.

3.2.1 Capital Investment

Cost Component	**Water Scrubbing System**	**Dry Technology System**
Equipment Cost	$500,000 – $1,000,000	$800,000 – $1,500,000
Installation & Infrastructure	$200,000 – $500,000	$250,000 – $600,000
Total Capital Cost	$700,000 – $1,500,000	$1,050,000 – $2,100,000

4. Conclusion

This comparative analysis demonstrates that dry technology offers superior performance, lower long-term costs, and greater environmental sustainability compared to water scrubbing.

- ✓ Higher pollutant removal efficiency (especially for PM 2.5, dioxins, and heavy metals).
- ✓ Significant cost savings over time, despite higher initial investment.
- ✓ Elimination of water usage and secondary waste generation.
- ✓ Better compliance with evolving emission regulations.
- ✓ Feasibility for large-scale implementation, but requires initial investment and regulatory adaptation.

Thus, transitioning to optimized dry technology is a strategic move for sustainable biomedical waste incineration. This study has demonstrated that transitioning to dry technology in biomedical waste incineration can lead to better environmental performance, lower operational costs, and improved compliance with emission regulations. The future of biomedical waste management lies in sustainable, water-free, and highly efficient air pollution control technologies. Governments, policymakers, and industry stakeholders should prioritize the transition to dry technology to ensure a cleaner, safer, and more sustainable waste management system.

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