

**EXPERIMENTAL ANALYSIS OF MUNICIPAL SOLID
WASTE BIODEGRADATION USING BIOREACTOR
LANDFILL IN TROPICAL CLIMATE**

TAMRU TESSEME ARAGAW



**DEPARTMENT OF CIVIL ENGINEERING
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LANDFILL IN TROPICAL CLIMATE**

by

TAMRU TESSEME ARGAWA

Department of Civil Engineering

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I dedicate this dissertation to my mother, Alganesh Assen. Thank you for always being so supportive of my studies and for your honest eagerness for all of my achievements. I know you would be very honored of this success.

CERTIFICATE

This is certify that the thesis entitled “**Experimental Analysis of Municipal Solid Waste Biodegradation Using Bioreactor Landfill In Tropical Climate**” being submitted by **Mr. Tamru Tesseme Aragaw** to the **Indian Institute of Technology Delhi**, for the award of the **degree of Doctor of Philosophy** is a record of the original bonafide research work carried by him under my guidance and supervision. The thesis work, in my opinion, has reached the requisite standards fulfilling the requirement for the **Degree of Doctor of Philosophy**.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

Dr. Sumedha Chakma

Professor

Department of Civil Engineering

Indian Institute of Technology Delhi

Hauz Khas, New Delhi-110016

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ABSTRACT

A bioreactor landfill has become popular recently in the developed countries that enhances the waste decomposition rate by the addition of regulated moisture. However, it has been given less attention and negligible applications by the tropical countries such as India and Ethiopia. It has been due to the limited data availability concerning the landfill bioreactor practices in the tropical conditions with existing solid waste. Hence, an attempt has been made to examine the effect of landfill bioreactors as a means of enhancing the waste biodegradation and assess their applicability in tropical climatic condition.

The study presented the bioreactor landfills operated with leachate recirculated mode suitable for the tropical climatic conditions. The study was carried out in three testing lysimeters in prismoidal shape and a control lysimeter in a circular shape. The bioreactors were operated under various combinations of biodegradation enhancement techniques such as the biological waste pretreatment, flushing technology, natural alkaline moisture addition, and waste shredding to evaluate the degradation rate. The leachate qualities, the gas production, and surface settlement were monitored for 270 days.

The overall biodegradation of pretreated wastes was accomplished in less than a year using the flushing bioreactor system. The high-water input indicated a negative impact on the pH buffers which delayed the methanogenesis process of the untreated waste. The landfilling of the pretreated waste was observed to improve the rapid surface settlement rate in the flushing bioreactor about 80%. The wastewater addition was found to solve the landfill buffering problems, reducing the landfill gas production period. The addition of greywater in the waste could delay the methanogenesis in the flushing bioreactor about a month compared to that of the addition of the wastewater. Further, in the early stage of waste degradation (0-6 months), the leachate quality, and the gas production varied significantly based on the initial moisture content and the pattern of waste placement. The landfill commissioning season was found as the core parameter for the waste decomposition processes along with the optimum moisture contents.

A point estimation method was found inappropriate for the comparative studies of the MSW stabilization stages for the different landfill scenarios. The leachate quality analysis results have indicated that the statistical interference method can be a reliable device to compute and rank the pollution potential of the landfills with a high degree of confidence. Further, an analytical based artificial neural network (ANN) model was developed to simulate the

organic pollutant concentrations in the leachates. The ANN input parameters were formulated analytically based on the governing equation which considering the landfill as a single fully-mixed reactor. Three processes were undertaken: (1) The dissolution of organic matter from solid to liquid phases; (2) the attenuation of the dissolved organic matter from the substrates utilization by the microorganisms and flushing; (3) the effect of the pH, temperature, and the moisture contents on the overall processes in the landfills. The linear regression analysis results suggested that the neural network based analytical model had a promising capacity to simulate the organic pollutants in the leachate within an acceptable degree of error. Thus, it could also help to monitor the long-term organic pollutant concentrations in the leachate considering the time without intensive laboratory examination at the landfill sites.

In conclusion, the study has provided a possible technical solution for the treatment of solid wastes using landfill bioreactors along with the simple modeling tools to monitor long-term landfill emissions. This approach can be used in the tropical climate of developing countries to manage the problem of over increased municipal solid waste disposal.

सार

वेस्ट डेकोम्पोसिशन को विनियमित नमी के माध्यम से बढ़ाने के लिए हाल ही में विकसित देशों में बायोरेक्टर लैंडफिल लोकप्रिय हो गया है। हालांकि, इसे भारत जैसे ट्रोपिकल देशों द्वारा कम ध्यान और नगण्य अनुप्रयोग दिए गए हैं। ट्रोपिकल देशों में लैंडफिल बायोरेक्टर से संबंधित, सीमित डेटा उपलब्धता के कारण यह हुआ है। इसलिए, वेस्ट जैव-वर्गीकरण को बढ़ाने और ट्रोपिकल क्लाइमेट स्थिति में उनकी प्रयोज्यता का आकलन करने के साधन के रूप में लैंडफिल बायोरेक्टरों के प्रभाव की जांच करने के लिए एक प्रयास किया गया है।

इस अध्ययन में ट्रोपिकल क्लाइमेट की स्थितियों में कार्यान्वयन के संबंध में पुनर्वितरण के साथ संचालित बायोरेक्टर लैंडफिल प्रस्तुत किए गए। अध्ययन प्रिज्मॉयडल आकार के तीन परीक्षण लयसीमेटर्स और एक गोलाकार आकार के नियंत्रण लयसीमेटर्स में किया गया था। बायोरेक्टरों को बायोडिग्रेडेशन एन्हांसमेंट तकनीकों के विभिन्न संयोजनों के तहत संचालित किया गया, जैसे कि जैविक वेस्टवाटर प्रत्यारोपण, फ्लशिंग प्रौद्योगिकी, प्राकृतिक क्षारीय नमी, और कचरा कटाव में। 270 दिनों के लिए लीचेट क्वालिटी, गैस उत्पादन, और सरफेस सेटलमेंट की निगरानी की गई।

प्रत्याशित अपशिष्टों का समग्र बायोडिग्रेडेशन फ्लशिंग बायोरेक्टर प्रौद्योगिकी में एक वर्ष से भी कम समय तक पूरा किया गया। हाई वाटर इनपुट ने पीएच बफर पर नकारात्मक प्रभाव डाला, और इसके साथ वेस्टवाटर की मेथनोजेनेसिस प्रक्रिया में देरी हुई। प्रत्याशित वेस्ट की लैंडफिलिंग से सरफेस सेटलमेंट दर में 80% सुधार देखा गया। वेस्टवाटर को ऐड करने से लैंडफिल बफरिंग समस्याओं को हल करने के लिए पाया गया, जो लैंडफिल गैस उत्पादन अवधि को कम करता था। कचरे में ग्रेवॉटर ऐड करने पर वेस्टवाटर की तुलना में लगभग एक महीने, मेथनोजेनेसिस में देरी पायी गयी। इसके अलावा, वेस्ट अवक्रमण (0-6 महीने) के शुरुआती चरण में, लीचेट गुणवत्ता, और गैस उत्पादन, प्रारंभिक नमी की मात्रा और वेस्ट प्लेसमेंट के पैटर्न के आधार पर महत्वपूर्ण रूप से भिन्न पाए गए। लैंडफिल कमीशन सीजन और ऑप्टिमम नमी की मात्रा, वेस्टवाटर डेकोम्पोसिशन प्रक्रियाओं के मूल पैरामीटर के रूप में पाया गया था।

पॉइंट एस्टिमेशन मेथड विभिन्न लैंडफिल परिदृश्यों के लिए एमएसडब्ल्यू स्थिरीकरण चरणों के तुलनात्मक अध्ययन के लिए अनुचित पाया गया। तुलनात्मक अध्ययन के नतीजे बताते हैं कि स्टैटिस्टिकल इंटरफेरेंस विधि लैंडफिल की प्रदूषण क्षमता की गणना और रैंकिंग के लिए एक विश्वसनीय उपकरण हो सकती है। इसके अलावा, लीचेट्स में कार्बनिक प्रदूषक सांद्रता को अनुकरण

करने के लिए एक विश्लेषणात्मक आर्टिफीसियल न्यूरल नेटवर्क (एएनएन) मॉडल विकसित किया गया था। एएनएन इनपुट पैरामीटर को अनलिटिकलिकल्ली तैयार किया गया, जो लैंडफिल को एक पूरी तरह से मिश्रित रिएक्टर के रूप में देखते हुए, तीन प्रक्रियाएं की गईं: (1) ठोस से तरल चरणों तक जैविक पदार्थ का विघटन; (2) सूक्ष्मजीवों और फ्लशिंग द्वारा सब्सट्रेट उपयोग से भंग कार्बनिक पदार्थ की क्षीणन; (3) लैंडफिल में समग्र प्रक्रियाओं पर पीएच, तापमान और नमी मात्रा का प्रभाव। लीनियर रिग्रेशन एनालिसिस के नतीजे बताते हैं कि आर्टिफीसियल न्यूरल नेटवर्क आधारित विश्लेषणात्मक मॉडल में स्वीकार्य डिग्री के भीतर लीचेट में कार्बनिक प्रदूषक अनुकरण करने की एक आशाजनक क्षमता थी। इस प्रकार, यह लैंडफिल साइटों पर गहन प्रयोगशाला परीक्षा के बिना समय पर विचार करते हुए लीचेट में दीर्घकालिक कार्बनिक प्रदूषक सांद्रता की निगरानी करने में भी मदद कर सकता है।

अंत में, अध्ययन ने दीर्घकालिक लैंडफिल उत्सर्जन की निगरानी के लिए सरल मॉडलिंग टूल के साथ लैंडफिल बायोरेक्टरों का उपयोग करके सॉलिड वेस्टके उपचार के लिए एक संभावित तकनीकी समाधान प्रदान किया है। सॉलिड वेस्ट निपटान की समस्या का प्रबंधन करने के लिए विकासशील देशों के ट्रॉपिकल क्लाइमेट में इस दृष्टिकोण का उपयोग किया जा सकता है।

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LIST OF ABBREVIATIONS

Acronyms	Expanded form
ANN	Artificial neural network
APHA	American Public Health Association
BOD ₅	Five-Day Biological Oxygen Demand
BP	Back-propagation
BPA	Back-propagation algorithm
CI	Confidence interval
COD	Chemical Oxygen Demand
DF	Degree of freedom
CPCB	Central Pollution Control Board
Diff	Difference
DF	Degrees of freedom
EC	Electrical Conductivity
EC/ Council	European Commissions
EU	European Unions
FFBP	Feed-forward back propagation network
GC	Gas chromatograph
HRT	The hydraulic retention time
IIT-Delhi	Indian Institute of Technology Delhi
IPCC	Intergovernmental Panel on Climate Change
LFG	Landfill gas
LMBP	Levenberg-Marquardt Back-Propagation
MAD	Mean absolute deviation
MAPE	Mean absolute percentage error
MLP	Multi-layer perceptron
MSD	Mean squared deviation
MSE	Mean squared error
MSW	Municipal solid waste
ORP	Oxidation reduction potential
SPSS	Statistical Package for the Social Science
TKN	Total Kjeldahl Nitrogen
TDS	Total Dissolved Solids

TS	Total Solids
TSS	Total Suspended Solids
US	The United states
USEPA	United States Environmental Protection Agency
VFA	Volatile fatty Acids

Nomenclature

Cm	Centimetre
$C_{\max}$	The maximum observed organic pollutant concentration
$C(t)$	The dissolved organic pollutant concentration
$C^*(t)$	The concentration of substrate decomposed at time t
$^{\circ}\text{C}$	Degree centigrade
H_0	Null hypothesis statement
H_1	Alternative hypothesis statement
i	The first input neuron
k	The coefficient of mass transfer rate
K_d	The endogenous decay rate constant
K_s	The half-velocity constant
k_1	The rate constant
L	Litre
L_0	The initial leachable COD in the solid phase (kg)
L_t	The remaining leachable COD in the solid phase (kg) at time t
m	Meter
mg/L	Milligram per litre
mV	millivolts
N_0	The neurons number in the output layer
N_i	The neurons number in the input layer
n	The sample size
[P]	<i>Input matrix</i>
Q	The average water application rate
Q_i and Q_e	The influent and effluent flow rates
R	The correlation coefficient
r	The mass transfer rate

rg	The net microorganism growth rate
r_{su}	The substrate utilization rate
S	The concentration of growth-limiting substrate in leachate
S_{pooled}^2	The pooled variance,
S_1^2, S_2^2	The sample variances of the population 1 and the population 2
S_1 and S_2	The sample deviation of the population 1 and the population 2
T	The temperature
T_o	The standard normal distribution on the difference between the mean
$[T]$	Target matrix
X	The concentration of biomass in the reactor
X_i	The input data presented to the ANN
X_o	The initial microorganism concentration
$X_1, X_2, \dots, X_n$	The random sample 1
$\bar{X}$	Sample mean 1
x	The observed value
x_{min} and x_{max}	The minima and the maximum value of the parameter
x_N	The normalized value,
Y	The biomass yield
$Y_1, Y_2, \dots, Y_n$	The random sample 2
$\bar{Y}$	Sample mean 2
V	The bioreactor landfill volume
W_{ij}	The synaptic weight
w	The recirculated leachate volume
Z	A standard normal distribution
Z_o	The test statistic
Z_1	The normal distribution of the two independent samples

Greek alphabet

α	The significant level
β	The possibility of creating an error
γ	The ratio of leachable matter
η	The learning rate

θ_f	The field capacity of waste
θ_j	The bias term
μ	The true population mean
μ^*	The specific growth rate
μ_o	A particular regulatory limit
μ_1	The mean of the population 1
μ_2	The mean of the population 2
μ_m	The maximum specific growth rates
σ^2	The true population variance
σ	The true population standard deviation