

CARBON SEQUESTRATION FROM MUNICIPAL SOLID WASTE LANDFILL

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by

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CERTIFICATE

This is to certify that the thesis entitled "**Carbon Sequestration from Municipal Solid Waste Landfill**" being submitted by **Ms. Niharika Pandey** to the **Indian Institute of Technology Delhi**, India for the award of the degree of **Doctor of Philosophy** in Department of Civil Engineering is a record of the bonafide research work carried out by him under my guidance and supervision. She has fulfilled the requirements for the submission of this thesis, which to the best of my knowledge has reached the requisite standard.

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

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Niharika Pandey

Abstract

The present study is an attempt to access the carbon sequestration within the municipal solid waste landfill. The effort also has been made to understand the estimation of landfill gas emission and landfill gas migration pattern. Correlation analysis and principal component analysis have been explored to identify the possible source of metal contamination and landfill gas migration pattern while Enrichment Factor and Geochemical approaches have been exploited to analyze the data.

The objectives of this study were to improve carbon capture within the landfill, study the impact of mineral carbonation over the solid waste, estimation of carbon dioxide emission from the landfill and to understand the landfill gas migration pattern within the landfill.

Feasibility of carbon sequestration in alkaline waste was investigated using experiments in the laboratory. The main goal of this research was to improve mineral carbonation process in landfills and to optimize the carbonation process.

Alkaline waste is an attractive option for the sequestration of carbon. This mineral carbonation process is exothermic in nature hence, there is no any need of energy supply and the carbonated product obtained is stable. Therefore, this mineral carbonation process gives the long-term solution for carbon capture. The present study is to determine the carbon sequestering potential of alkaline waste. To improve the understanding of mineral carbonation process in landfill condition feasibility studies based on landfill condition was performed in the laboratory. Based on limited knowledge of landfill, Simulated Landfill Reactors were constructed for the experimentation.

The growing urbanization in India and change in lifestyle and food habits results in growing challenge in a massive increase of waste and its composition. It is estimated that more than 55 million tons MSW is generated per year in India. This waste is collected from sources and dumped into the landfill, where it degraded and release carbon dioxide and methane gas predominantly. In the year, 2010 per capita MSW generation was 0.79 kg/day and the corresponding per capita CO₂ emission rate was found 1.64 metric tons that will scale up 3 - 5 metric tons in the year 2030 for 0.97 kg/day/capita waste. This carbon dioxide emission can be estimated by various models like Stoichiometric model, Land GEM model, Default model etc. Here in this study, Land GEM model and Default model were used for gaseous emission from the landfill. The site selected for the gas estimation, were Okhla landfill, Bhalswa Landfill and Gazipur landfill. Out of all the three landfill, Gazipur landfill accepts the highest amount of waste hence; the gaseous emission is quite high from Gazipur landfill in compare to Okhla landfill and Bhalswa landfill. The CO₂ gas emission rate from all the three landfill was calculated and found as Gazipur landfill > Bhalswa landfill > Okhla landfill.

The landfill gas migration pattern was also studied in Simulated Landfill Gas Migration Reactor. This study shows that the landfill gas concentration is high in Middle Layers of the landfill followed by Bottom Layers and Top Layers of the landfill.

Keywords: Carbon Sequestration; Municipal Solid waste; Construction and Demolition waste; Carbon Dioxide gas; Light and Heavy Metals; Geochemical Index; Enrichment Factor; Land GEM model; XRD analysis; SEM; EDX; Proximate Analysis, Ultimate Analysis

सारांश

वर्तमान अध्ययन नगरो में ठोस अपशिष्ट लैंडफिल (भराव क्षेत्र) में बढ़ते हुए कार्बन ग्रहण को समझने का एक प्रयास है। इसमें लैंडफिल गैस उत्सर्जन एवं लैंडफिल गैस फैलाव के स्वरूप को भी समझने का प्रयास किया गया है। सहसंबंध विश्लेषण और प्रमुख घटक विश्लेषण का प्रयोग धातु संदूषण के सम्भाव्य स्रोत और लैंडफिल गैस फैलाव स्वरूप का अन्वेषण करने के लिए है जबकि संवर्धन घटक एवं जिओकेमिकल सूचकांक का प्रयोग आंकड़े के विश्लेषण के लिए किया गया है।

इस अध्ययन का उद्देश्य लैंडफिल में कार्बन ग्रहण को बढ़ाना, ठोस अपशिष्ट पर खनिज कार्बनीकरण के प्रभाव का अध्ययन करना, लैंडफिल से उत्सर्जित कार्बन डाई ऑक्साइड की गणना करना और लैंडफिल के अंदर लैंडफिल गैस के फैलाव को समझाना था।

क्षारीय अपशिष्ट में कार्बन ग्रहण करने की सम्भाव्यता प्रयोगशाला में प्रयोगों का उपयोग कर जाँची गई। इस शोध का मुख्य लक्ष्य लैंडफिल में खनिज कार्बनीकरण की प्रक्रिया में सुधार और कार्बनीकरण प्रक्रिया को अनुकूल बनाना था।

क्षारीय अपशिष्ट कार्बन को ग्रहण करने के लिए एक आकर्षक विकल्प है। खनिज कार्बनीकरण प्रक्रिया की प्रकृति ऊष्माक्षेपी है। अतः यहाँ किसी ऊर्जा आपूर्ति की आवश्यकता नहीं है और कार्बनीकृत उत्पाद स्थायी है। इसलिए यह खनिज कार्बनीकरण प्रक्रिया कार्बन संश्लेषण का दीर्घकालिक समाधान देती है। वर्तमान अध्ययन क्षारीय अपशिष्ट के कार्बन अवशोषण क्षमता का निर्धारण करने के लिए है। लैंडफिल में होने वाली खनिज कार्बनीकरण प्रक्रिया की समझ को विकसित करने के लिए प्रयोगशाला में कृत्रिम लैंडफिल परिस्थिति में सम्भाव्यता अध्ययन किया गया। लैंडफिल के सीमित ज्ञान के आधार पर, प्रयोग के लिए कृत्रिम लैंडफिल रिएक्टर्स बनाया गया।

भारत में बढ़ते हुए शहरीकरण, जीवन शैली परिवर्तन और खानपान की आदतों में बदलाव के परिणामस्वरूप अपशिष्ट के संघटन में परिवर्तन और मात्रा में वृद्धि जैसी समस्या उत्पन्न हो गयी। अनुमान अनुसार भारत प्रति वर्ष लगभग 55 मिलियन टन अपशिष्ट उत्पन्न करता है। यह अपशिष्ट स्रोत से इकट्ठा करके लैंडफिल में फेंका जाता है जहाँ पर यह अपशिष्ट नष्ट होकर मुख्यतः कार्बन डाई ऑक्साइड और मीथेन गैस उत्पन्न करता है। वर्ष 2010 में प्रति व्यक्ति अपशिष्ट उत्पादन 0.79 किलोग्राम प्रतिदिन एवं इसके सापेक्ष प्रति व्यक्ति कार्बन डाई ऑक्साइड उत्सर्जन दर 1.64 मीट्रिक टन था। जो अब वर्ष 2030 में 0.97 किलोग्राम प्रतिदिन प्रति व्यक्ति एवं प्रति व्यक्ति कार्बन डाई ऑक्साइड उत्सर्जन दर 3 - 5 मीट्रिक टन होने की संभावना है।

कार्बन डाई ऑक्साइड उत्सर्जन की गणना Stoichiometric Model, Land GEM Model एवं Default model द्वारा की जा सकती है। लैंडफिल से उत्सर्जित गैस के अध्ययन के लिए Land GEM Model एवं Default model का प्रयोग किया गया है। गैस उत्सर्जन की गणना के लिए ओखला, भलस्वा और गाज़ीपुर लैंडफिल स्थान चुने गए। इन सभी लैंडफिल में से गाज़ीपुर लैंडफिल सर्वाधिक अपशिष्ट वाला क्षेत्र रहा है, इसलिए इस लैंडफिल में ओखला और भलस्वा लैंडफिल की तुलना में गैस उत्सर्जन ज्यादा होता है। कार्बन डाई ऑक्साइड उत्सर्जन दर की गणना तीनों लैंडफिल के लिए की गयी और इसे गाज़ीपुर लैंडफिल > भलस्वा लैंडफिल > ओखला लैंडफिल के अवरोही क्रम में पाया गया।

लैंडफिल गैस फैलाव पैटर्न का अध्ययन भी कृत्रिम लैंडफिल गैस फैलाव रिएक्टर में किया गया था। इस अध्ययन से पता चलता है कि लैंडफिल गैस सघनता सबसे ज्यादा मध्य में और उसके बाद निचले और ऊपरी भाग में होती है।

कीवर्ड्स : कार्बन अधिग्रहण; नगरपालिका का ठोस अपशिष्ट; निर्माण और विध्वंस अपशिष्ट; कार्बन डाई ऑक्साइड गैस; हल्की और भारी धातु; जियो-केमिकल सूचकांक; संवर्धन घटक; Land GEM Model ; एक्स आर० डी० विश्लेषण; एस० ई० एम०; ई डी एक्स; अनुमानित विश्लेषण, अंतिम विश्लेषण।

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ABBREVIATION

AAS	Atomic Absorption Spectrophotometer
ASTM	American Society for Testing and Material
BIS	Bureau of Indian Standards
BOD	Biological Oxygen Demand
C&D	Construction and Demolition
C/N	Carbon and Nitrogen ratio
CAGR	Compounded Annual Growth Rate
CCS	Carbon Capture and Storage
CDH	Central Drug House
CHNS analyzer	Carbon, Hydrogen, Nitrogen and Sulphure analyzer
COD	Chemical Oxygen Demand
Conc.	Concentration
CPCB	Central Pollution Control Board
DM	Dry Matter
EDX	Energy- dispersive X-ray Spectroscopy
EF	Enrichment Factor
GDP	Gross Domestic Productivity
GHGs	Greenhouse Gases
GWP	Global Warming Potential
HI ash	Hospital Incineration ash
HPLC	High-Performance Liquid Chromatography

HRT	Hydraulic Retention Time
ICDD	International Centre for Diffraction Data
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
K	Methane Generation Rate
Kg	Kilogram
kg	kilogram
L ₀	Methane generation Capacity
Land GEM	Landfill Gas Emission Model
LFG	Landfill Gases
MCD	Municipal Corporation of Delhi
mg	Milligram
mg/l	Milligram per liter
ml	Milliliter
mm	Millimeter
MO	Metal oxide
MOEF	Ministry of Environment and Forests
MSW	Municipal Solid Waste
MT	Metric Tones
Mv	Milli volt
NCR	National Capital Region

NMOCs	Non-methane organic compounds
PCA	Principal component analysis
PPM	Part Per Million
PUF	Polyurethane Foam
R	Correlation
RDF	Refused Derived Fuel
S	Sample Point
SEM	Scanning Electron Microscopy
SPSS	Statistical Package for the Social Sciences
Sq.	Square
TDS	Total Dissolved Solid
Tg	Teragram
TG/DSC	Thermogravimetric and differential scanning calorimetry
TKN	Total Kjeldahl Nitrogen
TPD	Tonnes per Day
TS	Total Solid
TVA	Total Volatile Acid
US EPA	United States Environmental Protection Agency
VFA	Volatile Fatty Acid
w/s ratio	Water and solid ratio
WHO	World health organization
XRD	X Ray Diffraction

XRD	X-Ray Diffraction
Chemical Symbol	
Ag_2SO_4	Silver Sulphate
Al_2O_3	Aluminum Oxide
$\text{Ca Mg (CO}_3)_2$	Calcium Magnesium Carbonate
Ca(OH)_2	Calcium Hydroxide
Ca_2SiO_4	Calcium Silicate
CaSiO_3	Wollastonite
CaCO_3	Calcium Carbonate or Calcite
$\text{CaFe (CO}_3)_2$	Calcium Iron Carbonate
CaO	Calcium Oxide
CaSiO_3	Calcium Silicon Oxide
CH_4	Methane (gas)
CO_2	Carbon dioxide (gas)
CuSO_4	Copper Sulphate
Fe (OH)_2	Ferrous Hydroxide
Fe_2O_3	Ferric Oxide
FeCO_3	Ferrous Carbonate
H_2O_2	Hydrogen Peroxide
H_2SO_4	Sulphuric acid
HNO_3	Nitric acid
$\text{K}_2\text{Cr}_2\text{O}_7$	Potassium Dichromate

K_2SO_4	Potassium Sulphate
$MgCO_3$	Magnesite
MgO	Magnesium Oxide
Mg_2SiO_4	Olivine
$Mg_3Si_2O_5(OH)_4$	Serpentine
Na_2CO_3	Sodium Carbonate
$NaHCO_3$	Sodium Bicarbonate
$(NH_4)_2CO_3$	Ammonium Carbonate
$NaOH$	Sodium Hydroxide
NH_4-N	Ammonium Nitrogen
SiO_2	Silicon Oxide
TiO_2	Titanium Oxide

Element Symbol

Al	Aluminum
C	Carbon
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
H	Hydrogen

K	Potassium
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
O	Oxygen
P	Phosphorous
Pb	Lead
S	Sulphure
Zn	Zinc

LIST OF NOTATION

0°C	Degree Celsius
T	Average Time
I_{geo}	Geochemical Background Value
S1 to S9	Sampling sites
$(M_e/F_e)_{\text{Background}}$	Geochemical background value of metal to F_e ratio
$(M_e/F_e)_{\text{Sample}}$	Metal to F_e ratio in the sample of interest
2θ	Peak Position
B	Bottom layer
H_1	Sampling point at Bottom Layer
H_2	Sampling point at Middle Layer
H_3	Sampling point at Top Layer
I_{geo}	Geo-accumulation Index
I_{obs}	Observe Intensity
M	Middle Layer
T	Top layer
Q_{CH_4}	annual methane generation in the year of calculation
i	yearly time increment
$t_{i,j}$	age of the j^{th} section of waste M_i accepted in the i^{th} year
L_0	potential methane generation
M_i	mass of waste
k	methane generation constant

j	0.1-year time increment
n	Difference in year of the calculation and initial year of waste acceptance
$(M/X)_{\text{Sample}}$	Metal to X ratio in the sample of interest
$(M/X)_{\text{Background}}$	EF background value of metal to X ratio
p	Partial Pressure