CARBON SEQUESTRATION FROM MUNICIPAL SOLID WASTE LANDFILL

NIHARIKA PANDEY

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

FEBRUARY 2017

CARBON SEQUESTRATION FROM MUNICIPAL SOLID WASTE LANDFILL

by

NIHARIKA PANDEY

DEPARTMENT OF CIVIL ENGINEERING

Submitted

In fulfillment of the requirement of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

FEBRUARY 2017

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.

Date

New Delhi

(Dr. Arvind K. Nema)

Professor

Department of Civil Engineering

Indian Institute of Technology Delhi

New Delhi- 110016, India

Acknowledgements

I would like to express my deep sense of gratitude and heartfelt devotion to my esteemed supervisor Prof. Arvind K. Nema for his parental care, untiring supervision, perpetual encouragement and staunch motivation, intellectual acumen, academic co-operation and avid suggestions throughout this work. No amount of appreciation can measure my deep gratitude and indebtedness to him for his continuous patience and his kind gesture. It has been a great privilege for me to get an opportunity to be an association with him since the nascent phase of my academic career. His pertinent suggestion and crucial counseling during my long association with him have not only reformed and polished my ideas but also helped to groom up my overall personality.

I would also like to thank my Doctoral Committee Members, Prof. B.J. Alappat, Prof. K.C. Iyer and Prof. Kamal K. Pant for the trust, the insightful discussion, offering valuable advice, for support during the whole period of the study, and especially for the patience and guidance during the writing process.

I wish to record my indebtedness to Prof. Manoj Dutta, Head of Department, Department of Civil Engineering, IIT Delhi for all the facilities provided for conducting this research.

Sincere thanks are due to Mr. Ishwar Singh and Shukla jee who have been very kind in maintaining a suitable working atmosphere and providing me the necessary support in the environmental lab. Special thanks are also due to Mr. Sanjay Gupta and Mr. Rajeev Sharma for tier co-operative and assistance at every stage for the incessant supply of my research chemicals.

I have a galaxy of friends who have been the source of continuous joy during the course of this research and stood by me during periods of uncertainty. I also want to express my appreciation to the special team of lab-mates, without whose support and co-operation, it would have been impossible to successfully complete this work. I express my sincere thanks to all of them. The thesis would not have come to a successful completion, without their support.I deeply cherish and appreciate the way my friends cheered me up, and again, in this hard pursuit of knowledge and research.

I would especially like to thank my sisters Nirjharini (PCS) and Urjashvi for continuous help since the first day of Ph.D. writing and proofreading. They have always stood by me and I hold prayerful and loving wishes in my heart for their welfare, for all their well wishes.

This work would not have seen the light of the day without the understanding and unfailing support of my parents. The credit goes exclusively to my father Uma Shanker Pandey, his sincere advice, loving encouragement and moral support helped to see the work finish smoothly.The patience, understanding, cooperation and bearing with the worst of my moods extended throughout the work by him are greatly appreciated. No words can adequately express the sense of gratitude I owe to my mother Bina Pandey whose love and affection has been the only incentive for me to attain heights of success in life.

I would also like to acknowledge the valuable inputs made by the reviewers of this research thesis, which significantly helped me improve the research work and its presentation. Lastly, I thank all those who care for me. Not all may be mentioned here, but none is forgotten.

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 CO_2 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 CO_2 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 स्वरुप 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 स्वरुप 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 नही 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 परिणामस्वरुप 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 तीनो लैंडफिल के लिए की गयी और इसे गाजीपुर 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 डाइ ऑक्साइड गैस; हल्की और भारी धातु; जियो-केमिकल सूचकांक; संवर्धन घटक; Land GEM Model ; एक्स आर० डी० विश्लेषण; एस० ई० ऍम०; ई डी एक्स; अनुमानित विश्लेषण, अंतिम विश्लेषण।

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

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
$Ca\ Mg\ (CO_3)_2$	Calcium Magnesium Carbonate
$Ca(OH)_2$	Calcium Hydroxide
Ca_2SiO_4	Calcium Silicate
$CaSiO_3$	Wollastonite
$CaCO_3$	Calcium Carbonate or Calcite
$CaFe\ (CO_3)_2$	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
HNO3	Nitric acid
$K_2Cr_2O_7$	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
$(NH4)_2CO_3$	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

0^0C	Degree Celsius
T	Average Time
Igeo	Geochemical Background Value
S1 to S9	Sampling sites
$(M_e/F_e)_{Background}$	Geochemical background value of metal to F_e ratio
$(M_e/F_e)_{Sample}$	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
Igeo	Geo-accumulation Index
I_{obs}	Observe Intensity
M	Middle Layer
T	Top layer
Q_{CH4}	annual methane generation in the year of calculation
i	yearly time increment
$t_{i,j}$	age of the j^{th} section of waste Mi accepted in the i^{th} year
L_0	potential methane generation
Mi	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
$(M/X)_{Sample}$	Metal to X ratio in the sample of interest
$(M/X)_{Background}$	EF background value of metal to X ratio
p	Partial Pressure