

**MODEL FOR OPTIMIZED IRRIGATION SCHEDULING  
FOR TRANSPIRING HYDROPHILIC VEGETATIVE  
COVERS ON MUNICIPAL SOLID WASTE LANDFILLS**

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**DEPARTMENT OF CIVIL ENGINEERING  
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COVERS ON MUNICIPAL SOLID WASTE LANDFILLS**

*by*

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**Submitted**

**in fulfilment of the requirements of the degree of Doctor of Philosophy  
to the**



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**OCTOBER 2021**

## CERTIFICATE

This is to certify that the thesis entitled, “**MODEL FOR OPTIMIZED IRRIGATION SCHEDULING FOR TRANSPIRING HYDROPHILIC VEGETATIVE COVERS ON MUNICIPAL SOLID WASTE LANDFILLS**” being submitted by Mr. Shailendra Kumar Jain to the Indian Institute of Technology, Delhi, India, for the award of the degree of DOCTOR OF PHILOSOPHY, is a record of bona fide research work carried out by him under my supervision and guidance. This thesis work, in my opinion, has reached the standard, fulfilling the requirement of DOCTOR OF PHILOSOPHY degree. The research report and the result presented 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.



**(Shashi Mathur)**

**(Supervisor)**

I.I.T. Delhi

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## ABSTRACT

Landfill gas is a significant source of anthropogenic methane emissions and accounts for more than half of the greenhouse gas emissions from the waste sectors. In developing countries due to budget constraints, harvesting landfill gas for energy, which is the best mitigation option is not feasible. Thus, enhanced methane oxidation within vegetative landfill cover soils is considered an important secondary measure to reduce landfill methane emissions to the atmosphere. Methane oxidation within vegetative landfill cover is also an eco-friendly remediation technology which uses methanotrophs present in landfill cover for converting methane into carbon dioxide which is 28 times less potent than methane over a time horizon of 100 years. The effective implementation of this cost-effective emerging technology requires optimal moisture content within the vegetative landfill cover soil. Most of the current research deals with the methane oxidation modelling within cover and hydrological study of landfill cover. Management of optimal moisture content over landfill cover for enhancing the methane oxidation has received very little attention so far.

In this study, mathematical models are developed for prediction of moisture movement and methane oxidation within vegetative landfill cover. The soil moisture movement and uptake of soil water by roots within landfill cover is predicted first. The methane oxidation within landfill cover is simulated next using the observed plant-soil parameters and the moisture flow data simulated from the first part of the model. Furthermore, an attempt has been made to determine the optimum irrigation scheduling over landfill covers.

In the first part, a non-linear partial differential equation for variably saturated moisture flow, is solved numerically by finite difference technique using a backward difference scheme coupled with the Picard iteration method. The equation is solved using an initial water content distribution and a flux boundary condition that signifies rainfall, irrigation and

evapotranspiration. In continuation, the solution of methane oxidation equation involves a two-step explicit scheme. In the first step, the flux at the centre point of each node is determined explicitly. The concentration for the next time step is then obtained using the flux from the first step. Further, optimal irrigation scheduling is calculated on the basis of daily available moisture content within cover using the CROPWAT software.

Initially, the variable saturated moisture flow model is simulated with and without considering the water uptake by plants term (sink term). The results obtained are later compared with the experimental data available in literature to validate the model. The model is then applied to different scenarios for water uptake by roots for jatropha plant under various environmental conditions. Later, taking the monthly average actual weather data as an input parameter, the spatial variation of moisture content for the proposed vegetative landfill cover is obtained with various Evapotranspiration values. Further, a numerical parametric analysis is conducted for vegetative landfill covers over MSW landfill taking the thickness of the vegetative cover, Soil Type, Evapotranspiration and effect of irrigation over cover.

In the next part of the study, the oxidation model is simulated using the moisture data from the moisture simulation model within the vegetative landfill cover to compute the concentration of methane as well as the concentration of oxygen and carbon dioxide at each node and their movement within the vegetative landfill cover. Subsequently an optimal irrigation requirement over the landfill cover to increase the oxidation of methane within the cover is computed.

Finally, with different irrigation patterns over landfill cover, spatial and temporal variation of methane, carbon dioxide and oxygen is simulated. Furthermore, the results obtained show that if optimal irrigation over a vegetative landfill cover is resorted to, an increase in oxidation of methane can be achieved.

**Keywords:** Landfills, Greenhouse Gases (GHGs), Irrigation Scheduling, Landfill covers.

## सार

लैंडफिल गैस मानवजनित मीथेन उत्सर्जन का एक महत्वपूर्ण स्रोत है और अपशिष्ट क्षेत्रों से ग्रीनहाउस गैस उत्सर्जन के आधे से अधिक के लिए जिम्मेदार है।। बजट की कमी के कारण विकासशील देशों में ऊर्जा के लिए लैंडफिल गैस का संचयन, जो कि सबसे अच्छा शमन विकल्प है, व्यवहार्य नहीं है। इस प्रकार, वनस्पति लैंडफिल आवरण की मिट्टी में मीथेन ऑक्सीकरण को बढ़ाना वायुमंडल में लैंडफिल मीथेन उत्सर्जन को कम करने के लिए एक महत्वपूर्ण माध्यमिक उपाय माना जाता है। वनस्पति लैंडफिल आवरण के भीतर मीथेन ऑक्सीकरण भी एक पर्यावरण के अनुकूल उपचारात्मक प्रौद्योगिकी है जो मीथेन को कार्बन डाइऑक्साइड में बदलने के लिए लैंडफिल आवरण में मौजूद मीथेन भक्षण जीवाणुओं का उपयोग करती है जो १०० वर्षों के समय क्षितिज पर मीथेन की तुलना में पर्यावरण के लिए 28 गुना कम कम हानिकारक है। इस लागत प्रभावी उभरती हुई तकनीक के प्रभावी कार्यान्वयन के लिए वनस्पति लैंडफिल आवरण मिट्टी के भीतर इष्टतम नमी की आवश्यकता होती है। अधिकांश वर्तमान शोध आवरण के भीतर मीथेन ऑक्सीकरण मॉडलिंग और लैंडफिल आवरण के हाइड्रोलॉजिकल अध्ययन से संबंधित हैं। मीथेन ऑक्सीकरण को बढ़ाने के लिए लैंडफिल आवरण पर इष्टतम नमी के प्रबंधन पर अब तक बहुत कम ध्यान दिया गया है।

इस अध्ययन में, वनस्पति लैंडफिल आवरण के भीतर नमी की गति और मीथेन ऑक्सीकरण की भविष्यवाणी के लिए गणितीय मॉडल विकसित किए जाते हैं। पहले भाग में, मिट्टी की नमी की गति और लैंडफिल आवरण के भीतर जड़ों द्वारा मिट्टी में उपलब्ध पानी के उठाव की भविष्यवाणी की जाती है। तत्पश्चात लैंडफिल आवरण के भीतर मीथेन ऑक्सीकरण को पौधे-मिट्टी मापदंडों और मॉडल के पहले भाग से प्राप्त कृत्रिम नमी प्रवाह आकंड़ों का उपयोग करके अनुकूलित किया जाता है। इसके अलावा, लैंडफिल आवरण पर इष्टतम सिंचाई निर्धारण निर्धारित करने का प्रयास किया गया है।

पहले भाग में, परिवर्तनशील संतृप्त नमी प्रवाह के लिए एक गैर-रैखिक आंशिक अंतर समीकरण, पिकार्ड पुनरावृत्ति विधि के साथ मिलकर एक पिछड़े अंतर योजना का उपयोग करके परिमित अंतर तकनीक द्वारा संख्यात्मक रूप से हल किया जाता है। समीकरण एक प्रारंभिक जल सामग्री वितरण और एक प्रवाह सीमा शर्त है कि वर्षा, सिंचाई और वाष्पीकरण का प्रतीक का उपयोग कर हल किया है। निरंतरता में, मीथेन ऑक्सीकरण समीकरण के समाधान में दो-चरण की स्पष्ट योजना शामिल है। पहले चरण में, प्रत्येक नोड के केंद्र बिंदु पर प्रवाह स्पष्ट रूप से निर्धारित किया जाता है। अगली बार चरण के लिए एकाग्रता को पहले कदम से प्रवाह का उपयोग कर प्राप्त किया है। इसके अलावा, इष्टतम सिंचाई

निर्धारण की गणना क्रॉपवाट सॉफ्टवेयर का उपयोग करके कवर के भीतर दैनिक उपलब्ध नमी सामग्री के आधार पर की जाती है।

प्रारंभ में, परिवर्तनशील संतृप्त नमी प्रवाह मॉडल का पौधों की उपस्थिति एवं अनुपस्थिति में अनुरूपण किया जाता है। प्राप्त परिणामों की बाद में मॉडल को मान्य करने के लिए साहित्य में उपलब्ध प्रायोगिक आंकड़ों से तुलना की जाती है। मॉडल को विभिन्न पर्यावरणीय परिस्थितियों के तहत रतनजोत पौधे के लिए जड़ों द्वारा पानी उठाव करने के लिए विभिन्न परिदृश्यों पर लागू किया जाता है। बाद में, मासिक औसत वास्तविक मौसम आंकड़ों को निविष्ट मापदंड के रूप में लेते हुए, प्रस्तावित वनस्पति लैंडफिल आवरण के लिए नमी की स्थानिक भिन्नता विभिन्न वाष्पीकरण मूल्यों के साथ प्राप्त की जाती है। इसके अलावा, शहरी ठोस अपशिष्ट लैंडफिल पर वनस्पति लैंडफिल आवरण के लिए वनस्पति आवरण, मृदा प्रकार, वाष्पीकरण और आवरण पर सिंचाई के प्रभाव की मोटाई लेने के लिए एक संख्यात्मक मापदंड विश्लेषण किया जाता है।

अध्ययन के अगले भाग में, मीथेन की एकाग्रता के साथ-साथ प्रत्येक नोड पर ऑक्सीजन और कार्बन डाइऑक्साइड की एकाग्रता और उनके गति की गणना करने के लिए वनस्पति लैंडफिल आवरण के भीतर नमी अनुत्तरित मॉडल से नमी आंकड़ों का उपयोग करके ऑक्सीकरण मॉडल का अनुकरण किया जाता है। इसके बाद आवरण के भीतर मीथेन के ऑक्सीकरण को बढ़ाने के लिए लैंडफिल आवरण पर इष्टतम सिंचाई आवश्यकता की गणना की जाती है।

अंत में, लैंडफिल आवरण पर विभिन्न सिंचाई प्रतिरूप के साथ, मीथेन, कार्बन डाइऑक्साइड और ऑक्सीजन की स्थानिक और अस्थायी भिन्नता का अनुकरण किया जाता है। इसके अलावा, प्राप्त परिणामों से पता चलता है कि यदि वानस्पतिक लैंडफिल आवरण पर इष्टतम सिंचाई का सहारा लिया जाता है, तो मीथेन के ऑक्सीकरण में वृद्धि प्राप्त की जा सकती है।

**संकेतशब्द:** लैंडफिल, ग्रीनहाउस गैसों, सिंचाई निर्धारण, लैंडफिल आवरण।

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