Adjustment method of aeration system operation and it's application in landfill.

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ABSTRACT: Aeration systems are operated continuously and efficiently to create an environment with sufficient oxygen in landfills and to guarantee landfill aerobic repair. The key to designing aeration systems is using a uniform method to evaluate the reliability of the analysis and optimization of parameters of well distribution and operation. Based on the optimization model of air injection strength and the neural network prediction model of air injection well distribution, a method to adjust and control a landfill aeration system, called the Landfill Aeration System Adjustment Method (LASAM), is developed. LASAM is established to maximize the oxygen storage rate, which is the ratio of the oxygen concentration in the extraction well to the oxygen concentration in the injection well. This method was used in Jin Kou landfill, which was the first and biggest aeration project in China. This study was expected to provide theoretical evidence of and reference data for the highly active and safety operation of aeration systems in landfills.

RÉSUMÉ :Les systèmes d'aération sont exploités de façon continue et efficace pour créer un environnement contenant suffisamment d'oxygène dans les décharges et pour garantir la réparation aérobie des décharges. La clé de la conception des systèmes d'aération est d'utiliser une méthode uniforme pour évaluer la fiabilité de l'analyse et l'optimisation des paramètres de distribution et de fonctionnement des puits. Sur la base du modèle d'optimisation de la force d'injection d'air et du modèle de prédiction du réseau neuronal de la distribution des puits d'injection d'air, une méthode d'ajustement et de contrôle du système d'aération de la décharge a été développée. LASAM est établi pour maximiser le taux de stockage d'oxygène, qui est le rapport de la concentration d'oxygène dans le puits d'extraction à la concentration d'oxygène dans le puits d'injection. Cette méthode a été utilisée dans la décharge de Jin Kou, qui était le premier et le plus grand projet d'aération en Chine. Cette étude devrait fournir des preuves théoriques et des données de référence pour le fonctionnement très actif et sécuritaire des systèmes d'aération dans les sites d'enfouissement.

KEYWORDS: aeration rate, gas well, landfill, distribution

1 INTRODUCTION

Aeration technology has been the major method used to enhance the in-suit repair of landfill around the world (Ritzkowski and Stegmann 2012). Much higher content of oxygen within the landfill was depended on the reasonable design of gas well operation scheme, including flow rate and distribution of the wells, which contributed on the effectiveness of the aeration system.

In general, the aeration rate (AR) in full-scale was obtained by lab-scale test results. Moreover, the waste sample used in lab-scale aeration test was difficult to be the typical one, because of the upscaling effect. As the anisotropy of pore system and high water level in full scale landfill, the aeration rate used in landfill was smaller than that used in lab-scale (Gamperling 2011, Hrad 2013, Slezak 2015). Moreover, the aeration rate only was a reference value for the design of aeration system in full scale. How to offer the enough oxygen by gas wells and what methods to use were must be considered. However, there was no standard for reference about the aeration system design around the world.

The well spacing (WS) was obviously effected by the environment condition and structure inside the landfill. On the one hand, the chemical reaction between the injected oxygen and methane will occur in landfill body under aerobic condition, resulting in the oxygen and methane were consumed. At the same time, much heat was released when the aerobic environment build up. On the other hand, the pore system in waste body was very heterogeneous, resulting in gas flow significant depended on the preferential path in landfill (Liu 2016c).

In summary, the aeration scheme should be determined by the project conditions (better oxygen filling area and enough oxygen supply and operation safety and coordination between WS and AR) and the environmental factors (organic degradation degree and water distribution and anisotropy of the pore space) within landfill. We proposed a Landfill Aeration System Adjustment Method (LASAM), which could consider the typical conditions in the field site to predict and select the reasonable WS and AR, improving the degradation efficiency in the course of aeration, ensuring continued aeration in long-term and ample amount of the oxygen.

2 OPTIMIZATION METHOD

2.1 *Optimization Program*

The optimization program was given in Figure.1. The main points as follow: First step: the oxygen movement states in landfill should be given by using gas transport model, based on the project conditions. Second step: to calculate objective function of oxygen storage ratio (OSR) and to select WS and AR by using optimization theory and neural network. Third step: when the export OSR satisfied the reliability, the analysis and selection was completed. If not satisfied the reliability, coming into the second step(see Figure.1).

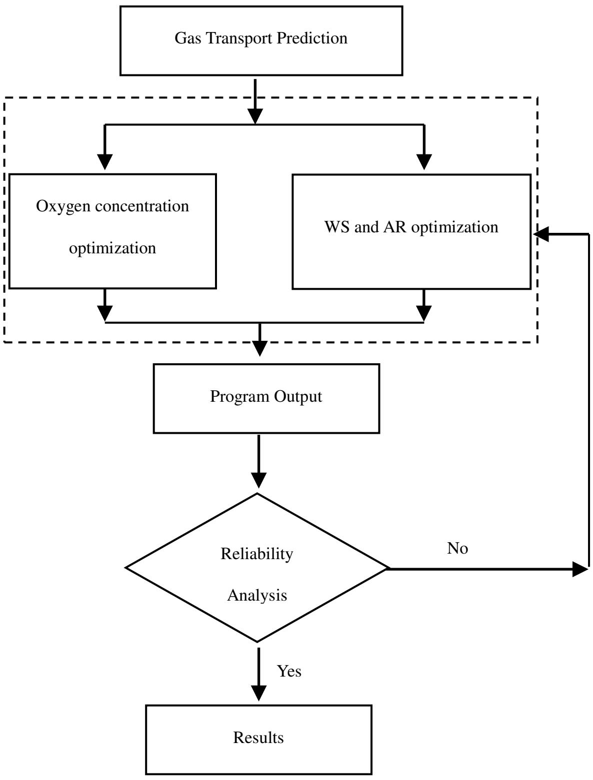

Figure 1. Flow chart of aeration scheme optimization.

2.2 *Optimization objective*

The maximum of the amount of oxygen in waste body was assumed as the optimization objective. Active aeration and off-gas extraction was selected in this method. A new index, oxygen storage ratio (OSR) was conducted for describe the amount of oxygen in waste body. It can be written by

$$\alpha_i = \frac{C_{E,i}}{C_{I,i}} \times 100\% \quad (1)$$

Where α_i is the OSR in ith well, is the lower limit, set as 75%; $C_{E,i}$ is the oxygen concentration from extraction well in ith well, $C_{I,i}$ is the oxygen concentration from injection well in ith well.

2.3 *Optimization Model*

The oxygen concentration in extraction well obviously depends on environment factors, optimization model of oxygen concentration could be written by

$$MaxC_{O2-out} = MaxC_{O2}(Q_{In}, Q_{Out}, k_s, D_{O_2}, k_f / k_m, D_f / D_m, w_f, V_{\max}, c_s, \lambda, k_b) \quad (2)$$

Where Q_{In} is the air injection flux (m3/h), Q_{Out} is the air extraction flux (m3/h), k_s is the gas permeability in landfill body (m2), D_{O_2} is oxygen effective diffusion coefficient (m2/s,) $V_{\max}$ is the maximum oxidation rate of methane (mol/m3/s), C_{O2-out} is the oxygen concentration in extraction well (%), could achieved by gas flow model.

There has obvious preferential path effect on gas transport in landfill body. This effect was attributed by using the quantitative method(Liu 2016c). Therefore, the preferential flow effect must be considered for prediction of the gases (oxygen and methane) evaluation during aeration process. The unified diffusion coefficient and unified permeability and total porosity could be described by:

$$D' = w_f \cdot D_f + (1 - w_f) \cdot D_m \quad (3)$$

$$k' = w_f \cdot k_f + (1 - w_f) \cdot k_m \quad (4)$$

$$n' = w_f \cdot n_f + (1 - w_f) \cdot n_m \quad (5)$$

Where D_f and D_m is the diffusion in fracture and matrix domain, respectively. k_f and k_m is the permeability in fracture and matrix domain, respectively. n_f and n_m is the porosity in fracture and matrix domain, respectively n' is the total porosity, assumed by 0.5. w_f is the relative volumetric proportion of the fracture pore system ($0 < w_f < 1$).

The oxidation rate of methane could be estimated with the Monod kinetics theory, could be written by (Yuan 2009)

$$R_{CH_4} = -V_{\max} \cdot \frac{1}{\left(1 + \frac{k_{m,m}}{C_{CH_4}}\right) \cdot \left(1 + \frac{k_{m,o}}{C_{O_2}}\right)} \quad (6)$$

$$R_{O_2} = 1.73 R_{CH_4} \quad (7)$$

Where, $V_{\max}$ is the maximum oxidation rate of methane (mol/ m3/s); C_{CH_4} and C_{O_2} is the methane and oxygen concentration, respectively (m3m-3); $k_{m,m}$ and $k_{m,o}$ is the half saturation constant of methane and oxygen (m3m-3).

Moreover, aerobic reaction reduced by air injection will release heat, resulting in a largely increases of the temperature in landfill. The prediction of the temperature should consider the conduction and generation of heat, could be expressed as (Lanini 2001),

$$Q_T = -\frac{A \cdot n'}{M_{O2}} \cdot k_b \cdot \exp(-\frac{E_a}{RT}) \cdot C_{O2} \quad (8)$$

Where ρ_s is the density of waste. c_s is the specific heat(J kg-1 K-1). . λ is thermal conductivity,(Wm-1K-1). A is aerobic reaction rate, 460e3(J/mol O2). M_{O2} is molar volume of oxygen, 24.8e-3 (m3/mol). k_b is biological kinetic constant,100~1000(s-1). E_a is activation energy, 38260 (J/mol). C_{O2} is the oxygen concentration (%).

The optimization of the gas wells distribution and AR could be conducted by using BP neural net model, to present intelligent selection and prediction and to enhance the accuracy of the export results. The parameters from equation (2) could be served as the import variables. The calculation program was presented by Xue and Liu (2014). The ranging of the import samples should be refer to the project condition.

The parameters in the optimization model were artificially specified at a range. They are,

$Q_{In}=Q_{Out}$=11000-45000 m3/h for total injection gas flux and total extraction gas flux, determined by injection rate and extraction rate from 0.05-0.2 L/(kg DM day)， H_{cover}=3m for cover thickness, V_{max} =0.001-0.03 mol/ m3/s for maximum oxidation rate of methane, k_s, k_{cover} is the gas permeability of waste body and cover, is the dispersion coefficient of waste body, respectively. The gas permeability of waste body was achieved by field site test, ranging from 2.7×10-13 to 6.5×10-12 m2.

The wet and dry thermal conductivity achieved by 0.184 and 0.038 W m-1 K-1, respectively (Nastev 2001). So, we selected λ=0.02-0.2 (W m-1 K-1). k_b=100~1000 s-1.

3 APPLICATION OF OPTIMIZATION METHOD

3.1 *Landfill description*

Jinkou landfill was located in Wuhan in China, closed in June 2005, has an area of 40 ha, where 5030000 m^3 municipal and building waste were deposited in four different sections. The aeration was estimated to operate in March 2014. This site will plan the 10^{th} China International Garden Expo after restoration. It was the first aeration projection to repair old landfill in full scale in China. The section 1 and 2 landfilled municipal solid waste and conducted aeration operation. The LASAM was applied in section 2, which was 14m thick and covered a 3m clay layer as final cover, with area of 14.93 ha and a volume of 2239500 m^3. The landfilled body was consist of two layer, the upper layer and lower layer depth were both 7 m, the landfilled time was 8 years and 15 years, respectively. Before aeration operation, the methane concentration was 32.7%, organic content was ranging from 7.6% to 11.3%, water level was ranging from 4.4 m to 8.4 m. The average temperature in waste body was from 26.5 ^oC to 32.7^oC.

3.2 *Constraint condition*

The upper bound was selected to 55oC in order to ensure the safety of the aeration system. The lower limit of the OSR was selected to 0.75.

3.3 *Program export*

The export results about the well distribution was show as follow:

WS=25.7m, gas flux in single well=93m3/h, maximum OSR = 89.6%.

200 extraction wells and 192 injection wells were installed . The aeration system consists of three injection blowers of and three extraction blowers with 6000m3/h, respectively. The injection and extraction blower was connected with gas analysis meter (cersm, WHRSM, China), respectively.

4 RESULTS AND DISCUSSION

Figure 2 shows the variation of OSR with time from the simulation and monitoring results. The measured OSR increased obviously and higher than the prediction results in the initial phase of the aeration system operation. This was mainly because much oxygen was collected by the pumping well as the preferential flow effect of the pore space network.

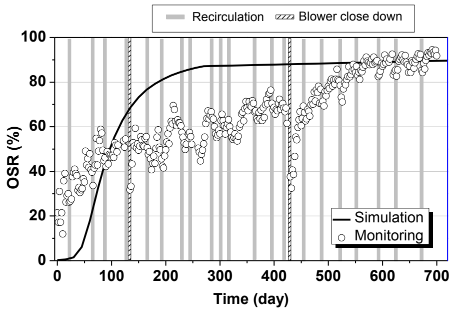

Figure 2. The variation of the OSR with aeration system operation.

The similar results also found in the field test of extraction-injection test(Ritzkowski 2006, Hrad 2013, Ritzkowski and Stegmann 2013). The slow increasing of the OSR occurs from 100 days to 550 days. It illustrated that the oxygen has been supplied the better aerobic environment and eliminated by chemical reaction. And the measured value was lower than the prediction value, because the strong reaction has been persisted in landfill. The trend of the OSR achieved stabilization after aeration operation 550 days.

5 CONCLUSIONS

We presented the LASAM to determine the WS and AR, which were selected from simulation results considered the relativity between the gases transport effected by environmental factors and temperature threshold. This method could be applied to design of aeration scheme in different projects, was used to achieve the WS and AR in Jinkou landfill in full scale in order to verify it's reliability.

The methane concentration has been increasing during the aeration process as the chemical reaction. The concentration of the oxygen and methane occurs at a higher and lower level in the middle and later aeration period, respectively. Those results attributed the reliability of development better oxygen environment in the waste body in full scale by using the aeration scheme from MWOAM, which provided one practical example in field site.

6 ACKNOWLEDGMENTS

This research was supported by the National Basic Research Program of China (973 Program) (2012CB719802);the Special Fund for Basic Research on Scientific Instruments of the National Natural Science Foundation of China (51625903, 51479194, 51509245,); Cross-disciplinary Collaborative Teams Program for Science, Technology and Innovation, Chinese Academy of Sciences. Hubei Outstanding Young key talents Program.

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