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Preliminary Tests and Full Scale Applications of In Situ Aeration

D. Rossetti[b], S. Cestaro[b], R. Cossu[a], R. Raga[a], M. Zane[b] and A. Costa[b]
[a] IMAGE Department, University of Padua, Italy; [b] Spinoff S.r.l., Padova, Italy

Abstract
The in situ aeration of Municipal Solid Waste landfills enhances the stabilization processes of biodegradable organic substances, resulting in an improvement of the quality of emissions. The full scale application of in situ aeration requires, besides the usual preliminary investigations for site characterization in terms of waste and emission quality, the evaluation of relevant parameters for the design of the in situ aeration plant, such as the radius of influence of air injection and gas extraction wells, the pressure field in the landfill body during the aeration process as well as the amount of carbon removable as CO_2 in the extracted gas. This paper provides some examples of preliminary tests carried out at lab scale and in situ in evaluation of the abovementioned parameters and two full scale applications and some results are briefly presented and discussed.

1 Introduction
In situ aeration by means of the AIRFLOW® system is a promising technology for the reduction of long term environmental impacts of landfills and for the remediation of old landfills. Over recent years several experiences of lab, pilot and full scale applications have been developed worldwide.

Proper investigations and preliminary tests are required in order to obtain all information necessary in designing an in situ aeration plant and in achieving an effective monitoring of the stabilization process during operation. Following customary investigation of site conditions in terms of current emissions, status of waste biological stabilization, expected impacts, etc., a mass balance of the organic carbon in the landfill should be determined, with the goal of evaluating the amount of carbon removable as CO_2 in the extracted gas during in situ aeration, comparing results with expectations from the traditional anaerobic landfill. Evaluation of the extractable carbon removable in biogas and leachate fluxes during the aeration processes has been carried out by means of lab scale column tests simulating the aerobic and anaerobic conditions in a landfill (Cossu et al., 2005, Ritzkowski et al., 2005); several comments and results are reported.

Design and installation of an aeration plant rely on the availability of important preliminary information with regard to parameters such as the radius of influence of air injection and gas extraction wells as well as pressure field in

the landfill body during the aeration process. This information may be obtained by means of specific in situ tests that are briefly described and the main results discussed. Moreover, two full scale aeration plants are described and results obtained after approx. one year of operation are presented.

2 Preliminary aeration tests

2.1 Lab scale tests

Lab scale tests have been conducted by means of column reactors (T1, T2, T3 and T4) kept at a constant temperature of 35°C, filled with waste collected by means of drillings or excavations from the landfill. The operative conditions of the 4 column reactors are briefly summarized: after a first anaerobic phase common for all reactors, T1 and T4 were run under aerobic conditions, with a water input simulating rainfall at a fixed liquid/solid ratio; column T2 was run under the same conditions, and in addition leachate recirculation was carried out. Column T3 was maintained under anaerobic conditions with water input at the same liquid/solid ratio. After 10 weeks of aeration, anaerobic conditions were once again established in columns T1 and T4, enabling assessment of the effects of aeration on a subsequent anaerobic phase.

The main goal of these tests was to compare the quality of emissions and degree of stabilization reached under the considered operative conditions. Moreover, an organic carbon mass balance was performed in order to evaluate the carbon discharge via gas and liquid phase in aerobic and anaerobic conditions.

During the column tests biogas and leachate were monitored and analyzed for the relevant parameters. The aerobic phase of the tests was stopped after reaching a significant decrease in biological activity in the columns, as demonstrated by very low concentrations of BOD and ammonia in leachate and CO_2 in the extracted gas.

Figure 1 shows the relationship between carbon removed with gas and oxygen consumed due to biodegradation in the aerated columns. Interpolation of these values provides a linear relationship between the two parameters. The mean angular coefficient of lines gives the carbon removal constant K_c^{gas} ($mgO_{2consumed}$/$mgC_{removed}$) expressed as the quantity of oxygen consumed for the removal of one unit mass of organic carbon. The potential of removable organic carbon can be calculated by the following relationship (Ritzkowski et al., 2005):

$$C_{REMOVABLE} = TOC_{GAS} + TOC_{LEACHATE}$$

where TOC_{GAS} and $TOC_{LEACHATE}$ represent the load of total organic carbon discharged with biogas (as CO_2) and leachate (TOC). Under aerobic conditions the most important process in carbon removal is gasification as CO_2. In fact, carbon balance carried out for the aerobic columns displayed a percentage of approx. 94-95% of carbon removed via the off-gas. Similar results are reported in Ritzkowski et al., 2005. A percentage of approx. 10% was obtained for the anaerobic column.

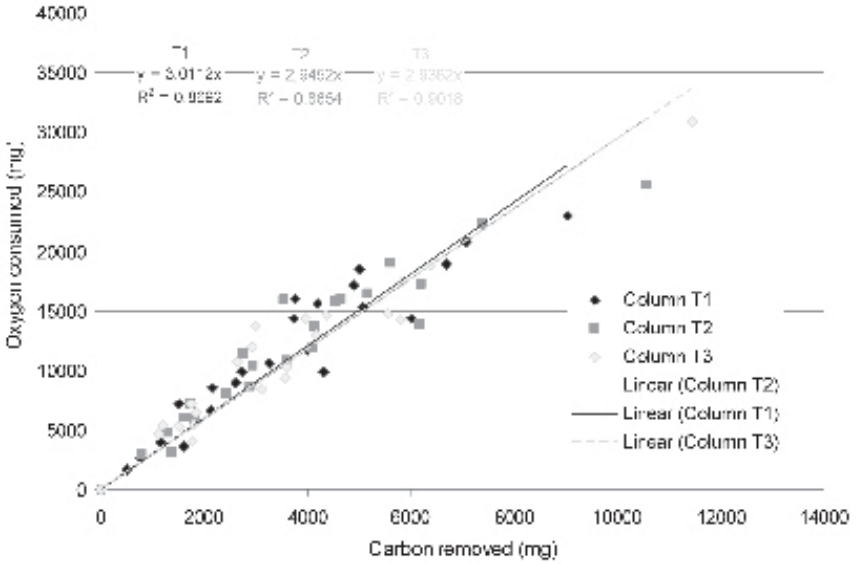


Fig. 1: Relationship between carbon removed as CO_2 in the extracted gas and consumed O_2.

By means of K_c^{gas} it is possible to calculate the total mass of oxygen per unit mass (TS, total solids) required to reach biological stabilization of waste, assuming that all degradable organic carbon is removed by means of gasification:

$$mass\,O_{2\,necessary} = \overline{K}_C^{gas} \cdot TOC_{GAS}$$

where TOC_{GAS} is the mass of carbon expected to be removed as CO_2.

When the flow rate of the in situ aeration plant is fixed, a first evaluation of the total quantity of air necessary, and consequently of the duration of operation, is possible. Obviously, a different behavior is observed between column tests and full scale application. A longer operation time respect to the calculated value should be taken into account due to:

- heterogeneity of the waste mass, causing the formation of preferential flow paths for the injected air and subsequent inhomogeneous distribution of oxygen and the presence of anaerobic zones in the aerated landfill;
- leakages through the surface cover, causing loss of oxygen from the system;
- underestimation of the removable carbon as CO_2 in the extracted gas in the column tests caused by the formation of preferential flow paths in the reactors, thus limiting the effects of aerobic conditions to only part of the investigated sample.

Factors determining the different behavior between columns and landfill can be evaluated during operation of the full scale plant by means of CO_2 measurements (carbon discharge with the gas) and TOC analyses on waste samples, as well as through comparison of results with those obtained in the lab.

2.2 In situ tests

The design of a full scale in situ aeration plant (AIRFLOW® system) must take into account the evaluation of parameters such as the radius of influence of air injection and gas extraction wells and pressure field in the landfill body during the aeration process. These can be determined using the results of field tests and by applying a mathematical model (Cestaro et al., 2005).

The model used is based on the analytic solution of flow equation tabulated by Hantush (1964), to achieve a homogeneous and anisotropic aquifer, bound at the bottom by an impermeable liner, on the top by a low permeability surface, and characterized by a two dimensional flow (radial and vertical) induced by the air injected/extracted from a well.

The pilot system used for in situ aeration tests consists in suitable injection/extraction and monitoring wells drilled in the landfill body. The latter are habitually placed along two orthogonal directions in order to measure the radial variations of the pressure with respect to the pressure registered in the injection/extraction well.

The pilot plant used for the test comprises a mobile unit equipped with two blowers, flow rate and gas composition measuring devices.

The findings of a case study are provided in this paragraph. The test area consists of three aeration wells and ten monitoring wells drilled into the waste mass.

Air was injected into or extracted from the waste mass through one aeration well at a time and pressure increase or decrease (ΔP) and variation of gas composition in the waste mass due to aeration were measured at each monitoring well during the test until steady-state conditions were reached. Figure 2 shows as an example the results of analysis of gas composition carried out at monitoring points M1, M2 and P3, at the respective distances of 6, 12 and 18 m from the injection well, with an air flow rate of 85 m^3/h.

Values measured to calculate pressure in the landfill body were used to calibrate a mathematical model in order to determine unknown parameters such as air permeability of the waste (k_a) and of the clay layer used as landfill top cover (k_A). The results obtained ($k_a = 2 \bullet 10^{-10}$ m^2, $k_A = 3 \bullet 10^{-15}$ m^2) enabled calculation of the theoretical air pressure distribution in the landfill and determination of the radius of influence of the air injection and gas extraction wells.

Figure 3 illustrates the theoretical pressure variation according to distance from the aeration well, calculated for different air flow rates using the abovementioned values of air permeability. Table 1 shows the results of evaluation of the radius of influence, intended as the maximum distance from the injection/extrac-

tion well at which a significant variation of pressure due to the aeration can be measured in the landfill body.

Correct evaluation of pressure distribution and of the well radius of influence is fundamental in ensuring a reliable calculation of the number and mutual distance of the wells needed in the aeration plant.

Tab. 1: Radius of influence of one air injection well on several parameters of air flow rate (Q).

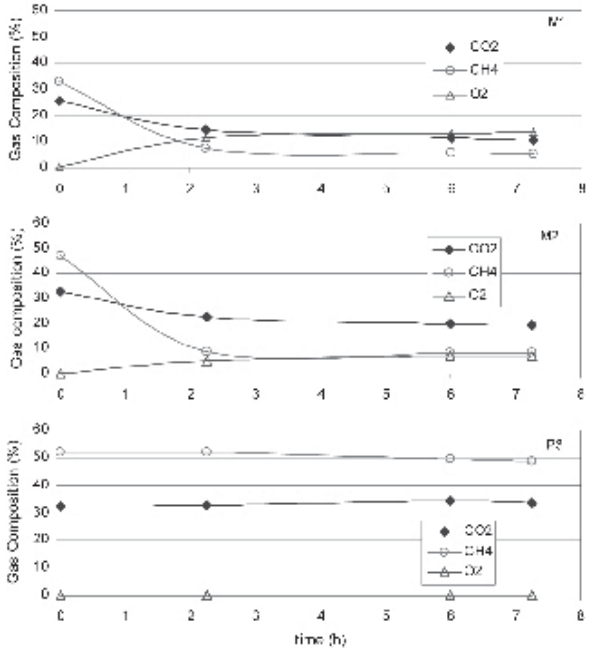


Fig. 2: Variation with time of the gas composition in the monitoring wells M1, M2 and P3, at the respective distances of 6,12 and 18 meters from the air injection well.

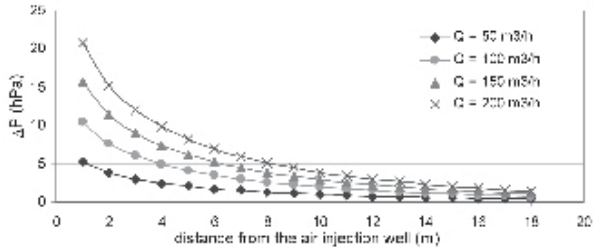


Fig. 3: Theoretical pressure (ΔP) distribution in the landfill body in the surroundings of the air injection well, for some values of the air flow rate (Q).

Q (m^3/h)	*Radius of influence (m)*
50	5
100	10
150	13
200	15

3 Full-scale applications

This chapter describes the results obtained after approximately one year of in situ aeration at two MSW landfills, indicated in the following as landfill C and landfill L, located in northern Italy.

Landfill C started operations in the seventies, the first sectors being built in former clay pits. The first sectors, where no synthetic barriers were foreseen, closed in 1983 and the new sectors were built with bottom liners according to the requirements of the new legislation. Over the following years landfill extension was carried out on the old sectors and operations continued until 2002. A similar situation was encountered for landfill L, built in the seventies in a former river bed and operated for the first 14 years without any artificial barriers at the bottom of the sectors. No leachate collection system had been installed in the old sectors of either landfill, thus presenting an increased risk of pollution of the groundwater. Subsequently, the need for remediation of the old part of the landfills arose and a project of in situ aeration was approved by municipalities and regional authorities and was started in both landfills.

3.1 Description of the plants

The in situ aeration plant at landfill C (Figure 4) will be built in installments. The first part involves a volume of approximately 60.000 m^3 of waste and consists in 11 gas extraction and 11 air injection wells positioned in four rows. The air injection/extraction unit comprises blowers purposely designed to guarantee the low pressure aeration at an adequate flow rate for every well. Ten monitoring wells equipped with three probes screened at different depths (6, 9 and 12 m) are positioned between the injection and the extraction wells. The exhaust gas is sent to biofilters before being released into the atmosphere. The in situ aeration plant of landfill L (Figure 5) involves a waste volume of approximately 200,000 m^3. It consists of 84 wells (56 gas extraction wells and 28 air injection wells) positioned in three rows, a central line of air injection wells and two external lines of gas extraction wells. Twenty-five monitoring wells equipped with two probes screened at the depths of 4 and 7.5 m are located between the aeration and extraction wells. In both landfills, the in situ aeration plant is equipped with a pneumatic leachate extraction system in order to keep the leachate head as low as possible in the landfill and thus increasing the efficiency of the aeration. The operation of the in situ aeration plants started in December 2005 for landfill C and in October 2005 for landfill L. Monitoring plans have been implemented and periodical analyses are made on waste samples and leachate, as well as on landfill gas and tempera-

ture in the landfill body, in order to constantly monitor the effects of the aeration and be able to periodically adjust the controls of the process as needed.

3.2 Results

The results obtained at landfill C after one year of plant operation are described below. Regarding the waste quality, two of the main parameters related to the stabilization, i.e. the Respiration Index (RI_4) and gas potential production (GB21) decreased during operations. After one year of operations the average RI_4 value had decreased from 7.5 to 2.8 mgO_2/gTS (63% reduction), and the average GB_{21} value had decreased from 20.9 to 7.1 Nl/kgTS (66% reduction) in comparison to values measured before start of aeration. A higher homogenization of RI_4 values after the operation was also observed. A decrease in variance was also observed on analyzing data, indicating that not only a decrease of values had occurred for the relevant parameters but also more homogenous characteristics had been reached for the waste in the different part of the landfill after one year of aeration.

With regard to gas quality, the composition of extracted gas (Figure 6) revealed an increase of oxygen concentration with time, together with a simultaneous decrease of methane concentration, indicating a good air flow from injection to extraction wells. This is confirmed by concentration trends observed at the monitoring points. During the first 6-7 months methane concentration decreased from 55-65% to 2-10%, whereas carbon dioxide and oxygen increased to 10-15% and 10-20% respectively. The CH_4/CO_2 ratio rapidly decreased to values lower than 1, indicating the development of aerobic degradation processes in the landfill body.

Effects of aeration were less visible in the leachate. A slight increase in nitrate concentration was observed while ammonia presented variable concentrations with a trend revealing an increase with an average value of approx. 1,800 mgN/l, respect to the initial 1,300 mgN/l. TVA and BOD_5 featured the most important decrease of approx. 30-40 % compared to initial concentration values.

An increase in ammonia at start of aeration was also observed in other experiences in Germany due to mobilization into the leachate phase of porous water containing dissolved and/or adsorbed NH4-N compounds (Ritzkowski and Stegmann, 2005) .

It should be underlined how the scarce influence of aeration on leachate was expected, implying the goal of removing old leachate from the landfill. The point is that following proper aeration of the landfill the emission potential of the waste is expected to be reduced in such a way that water, infiltrating throughout the landfill body due to rainfall, will be capable in the future of extracting negligible amounts of compounds or elements from wastes and producing a leachate of no concern for the specific environment.

A positive effect was also observed in the case of Landfill L, with a decrease of respiration index, showing a more homogeneous distribution in the landfill after one year of plant operation. The decrease of RI_4 was less dramatic than in landfill

C (from 4.4 to 3.4 mgO_2/gTS, reduction of 23%) although final values achieved are similar. The composition trend of extracted gas (Figure 7) shows a rapid decrease in methane concentration. After less than one month, CH_4 concentration dropped from 55% to 3-4%, while O_2 increased to values of approximately 18%. This trend is similar to that observed for the aeration plant in landfill C and indicates a good

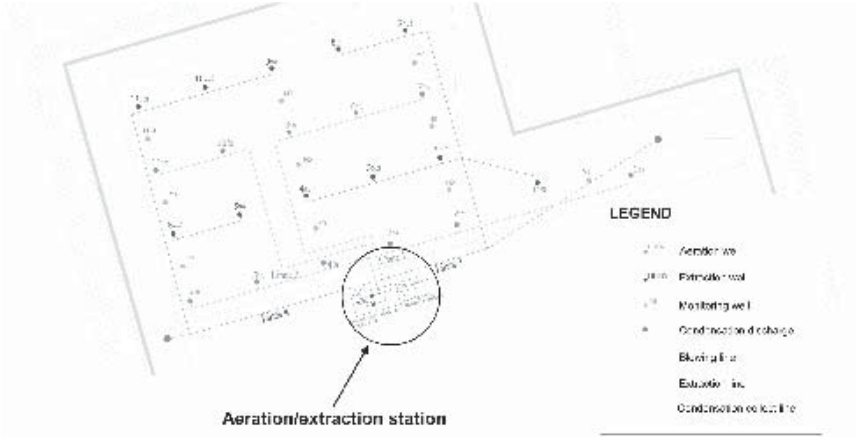


Fig. 4: Layout of the in situ aeration plant in landfill C.

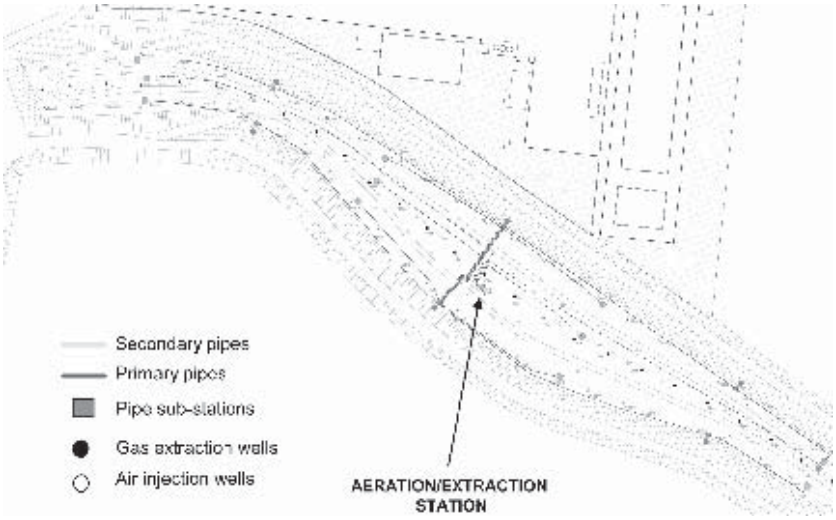


Fig. 5: Layout of the plant in landfill L.

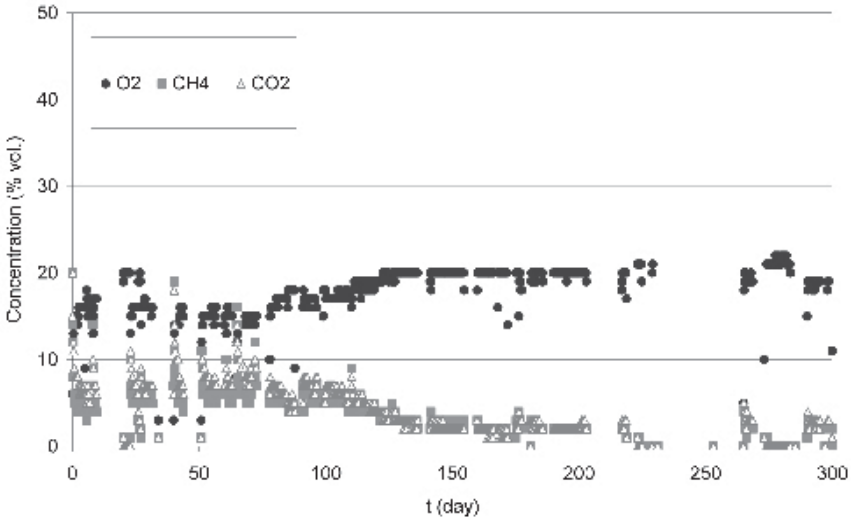


Fig. 6: Composition of extracted gas in landfill C.

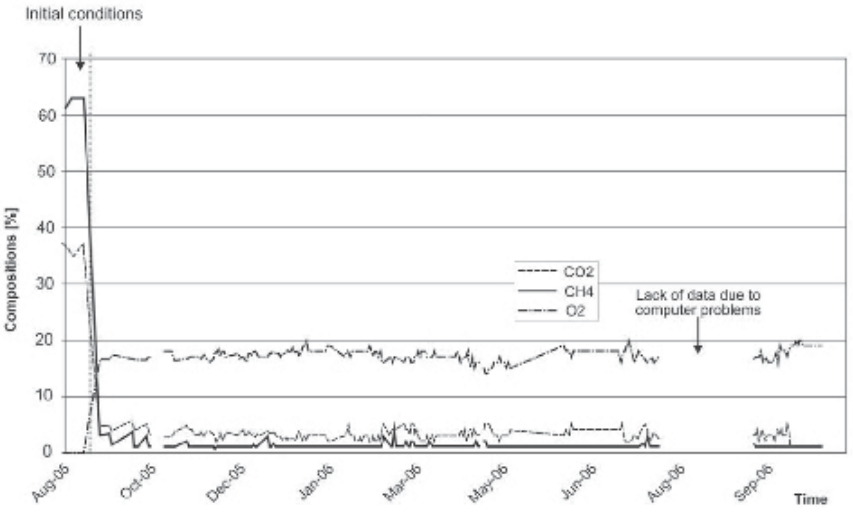


Fig. 7: Composition of extracted gas in landfill L.

flow of injected air towards the external extraction lines. With regard to leachate quality, the results obtained are similar to those obtained for landfill C. A decrease of TVA concentration from 700 to 350 mgC/l (with a reduction of 50%) was observed. Moreover, nitrate concentration increased, reaching values of approximately 200 mgN/l in several samples taken from the aeration wells. An increase in ammonia concentration was also observed in this landfill.

4 Conclusions

Proper investigations and preliminary tests are needed in order to obtain information to be taken into account on designing an in situ aeration plant.

Lab scale tests proved to be of use in simulating the aeration process and in providing information on the carbon mass balance, furthermore presenting the possibility to estimate the amount of air and time necessary to reach the required targets for biological stabilization of waste. A better comprehension of the relationship between the results of lab scale tests and those obtained in full scale applications is still needed in order to better apply information provided by preliminary investigations in the future.

In situ tests provide important information on physical properties of the waste and the dynamic of fluids inside the landfill. Design parameters as the well radius of influence and the pressure field subsequent to aeration were thus obtained and used in two currently operational full scale applications. Following the first year of aeration the results obtained are encouraging and will provide further data for the enhancement of these plants as well as of future installations.

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