BIODEGRADATION AT A LAND-FARMING SITE AT 14,000 FEET IN THE HIGH BOLIVIAN ALTIPLANO

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ABSTRACT

Approximately 30,000 m^3 of contaminated soil recovered from cleanup operations after a 29,000 barrel oil spill in the Desaguadero River (January 2000) was stored in temporary pits. Waste disposal plans explored several options for final disposal, including incineration and land farming. Initial concerns about the ability to landfarm the contaminated soil centered on the biodegradation potential at altitudes of 14,000 ft (4,300 m) and in a region with seasonally low day and nighttime temperatures. The Bolivian Altiplano has a semiarid climate where daily fluctuations of 15℃ in temperature are common while average temperatures range between –6 C (July) and 21.0℃ (November).

The technical experts at the Bolivian Ministry of Sustainable Development were reluctant to grant permission for Land Farming to be used at high altitude and instead insisted that all the contaminated soil be sent by truck across Bolivia to lower altitudes where the proposed a Land Farm was to be created. As an operational response a series of experiments was set up to demonstrate that indeed Land Farming was possible at high altitude. This paper presents the results of these experiments but it should be clearly noted that the testes were conducted under operational conditions without the rigour normally found in laboratory or scientific experiments.

Results showed that it was not only possible to deplete the total petroleum hydrocarbon (TPH) content from 40,000 ppm to below 1,000 ppm required by Bolivian law, but that it also could be completed within 4 months under specific technical conditions of the biodegradation process. Previous studies documented the formation of oil-mineral aggregates (OMAs) in the contaminated soils from the Rio Desaguadero spill[1]. We hypothesized that OMA formation and presence of aluminum polysilicate would provide an effective combination to increase the biodegradability of the soils under specific control conditions. This paper explains the high-altitude biodegradation process and the results of monitoring tests from the land farming under operational field conditions.

Key words: *biotreatment techniques, landfarming, biocells, natural degradation, physical and chemical treatment, assisted landfarming, oily soils.*

INTRODUCTION

At a crossing point of the Desaguadero River in Bolivia and during a flood event in January 2000, approximately 29,000 barrels of crude oil blended with condensate was accidentally released from a hole in the OSSA II pipeline[2]. The resulting impact of the area downstream included more than 400 km of river banks and 500 km^2 of flooded low lands on the Bolivian Altiplano. The 30,000 m^3 of contaminated material, was transported and stored in geomembrane lined waterproofed pits waiting for treatment[5].

Statistical analysis from 1960 to 1990 (Tables 1 and 2) show high variations in temperatures, ranging from –5.9 to 21°C in this region, due to the regional climatic conditions and the altitude of 14,000 feet (4,300_m)[6]. In light of these conditions (temperature, altitude, temperature gradient and low pressure) diverse opinions arose within the government monitoring authorities questioning the effectiveness of enhanced biodegradation techniques (bioremediation) as a mitigation strategy.

Table 1. Maximum monthly and annual average temperatures (°C)

Station	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Patacamaya	1960-90	19.4	19.2	19.1	18.8	19.5	15.7	15.8	16.8	18.0	20.2	21.1	20.2	18.5
Sica Sica	1960-90	16.9	16.0	16.2	16.1	15.1	12.8	12.8	14.3	16.0	17.7	18.4	17.9	15.8

Table 2. Minimum monthly and annual average temperatures (°C)

Station	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Patacamaya	1960-90	4.8	4.7	4.1	1.3	-2.9	-5.5	-5.9	-3.8	-0.5	1.4	3.0	4.4	0.4
Sica Sica	1960-90	5.6	5.1	4.8	3.1	0.6	-1.4	-1.5	0.4	2.4	4.0	4.8	5.4	2.8

Source: Climatologic study, TDPS system

BIOREMEDIATION SCIENCE

Bioremediation treatment takes place when a series of oxide-reduction reactions occur within target compounds in the presence of microorganisms. Microorgansims work faster and speed up the reaction if the conditions supporting them are improved. This can be done by the addition of oxygen, nutrients and / or increased temperature. The various methods used in this experiment were designed to see if manipulation of these factors could accelerate the rates of residual oil degradation under high altitude conditions of the Bolivian Altiplano.

METHODOLOGIES

In order to choose the most appropriate and economically viable technique, an evaluation of the following bioremediation techniques was made: Controlled Landfarming, Assisted Landfarming, Biocell, Natural Degradation and Physical-Chemical Treatment.

The average TPH of soils used in test cells was 40,660 ppm.. The initial content of microorganisms was 2,500 UFC (Colonies per 100 cm3), equivilent to 1344 UFC per gram of soil. (Reference for NMP method)

a) Landfarming A (One meter greenhouse membrane above the ground)

In the Landfarming A cell, the original nitrogen content was 0.17 ppm and phosphorus was 187.68 ppm. The carbon: nitrogen: phosphorus ratio in the initial samples was 100:1:0.1, indicating that in order to have an appropriate result, chemical compounds containing nitrogen and phosphorus were required. Ammonia phosphate solutions were prepared and added. Specific temperature control measures were not implemented in this cell.

On very cold days without the control of temperature, for about six hours the microorganisms did not act with the same effectiveness as when the soil temperature range was between 15 and 40°C. Thus the process was found to be slow.

A further problem was the poor adsorption of the phosphorus that had been introduced in the form of ammonia phosphate. Even with heavy mixing, a solution of 30 mg of ammonia phosphate per litre of water was required to create a Carbon : Nitrogen : Phosphorus ratio of 100:10:10.

b) Landfarming B (greenhouse membrane)

The experimental conditions were the same as in Landfarming A, but with a greenhouse membrane position 2 m over the cell to increase the average temperature and reduce temperature fluctuations.

c) Biocell (Artificial aeration and a greenhouse membrane one meter above the ground)

The biocell is a system that uses the introduction of additional oxygen via air pipes into the contaminated soil. The objective is to increase the number of microorganisms. Ammonia phosphate was added as in the previous two methods. Microorganisms were also added over time so that the content of microorganisms was much higher, starting at approximately 9,000 UFC equivilent to 4838 UFC per gram of soil. instead of the 2,500 UFC or 1344 UFC per gram of soil in other treatment cells. (This was done by taking a live sample of the same soil that was to be treated and preparing a culture to enhance the level of microorganisms.)

Levels of nitrogen, oxygen and phosporus were difficult to control in this method. To improve the infiltration of nitrogen, oxygen and phosphorus and to assure the appropriate flow of the ammonia phosphate solution inside the Biocell, the amount of air pumped had to be increased.

d) Assisted Landfarming (One meter greenhouse membrane plus aluminium polysilicate).

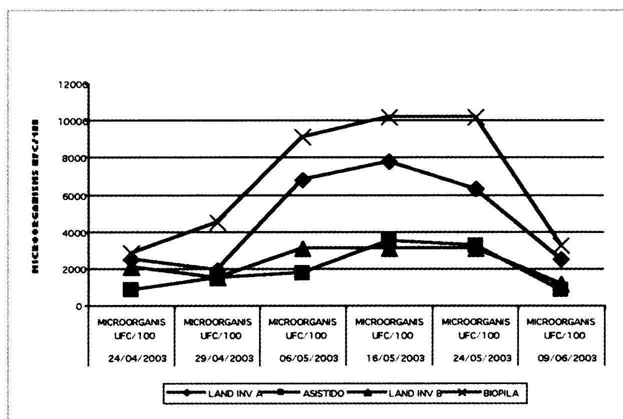
In the assisted landfarming cell a combination of microbiologic and physical-chemical mechanisms were used. An assisted landfarming cell was prepared to control the temperature and the levels of polysilicates) that could combine with the OMAs (Oil-Mineral Aggregates) in the contaminated soil[3]. (Thus the polysilicates acted as a reducer of the initial quantity of hydrocarbons reducing TPH levels to below 30,000 ppm.)

The chemical composition of the OMA and the polysilicate allowed greater evaporation of water from the oiled soil. The evaporated water condensed on the greenhouse membrane and precipitated back onto the soil. This movement of water helped the OMAs and the polysilicate to combine and create an exothermic reaction which it is thought heated the contaminated soil and allowed the microorganisms to work faster. This exothermic reaction was probably mediated by composting[4].

RESULTS

1. Growth of microorganisms.

Graph 1 reflects the growth in number of microorganisms and demonstrates the population of microorganisms is much higher after 21 days under biocell conditions, closely followed by landfarming with greenhouse A. Assisted Landfarming and Landfarming with the greenhouse B system showed the least growth in microorganisms.



GRAPH 1. MICROORGANISM VERSUS TIME

2. Temperature control

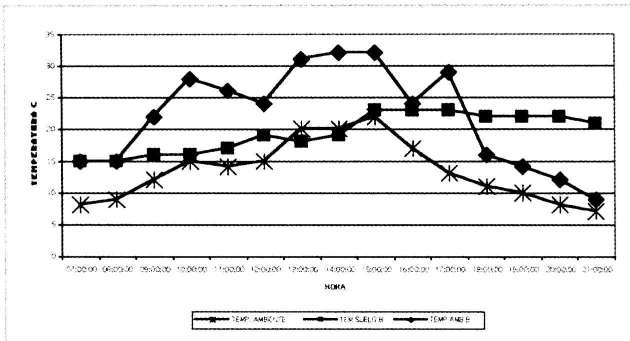
Graph 2 shows that the ambient temperature varied from -2.9 to 19°C. Low temperatures were associated with slow biodegradation rates. Biodegradation rates were higher in cells maintained at a temperature range between 15 to 33°C.

3. Temperature versus method

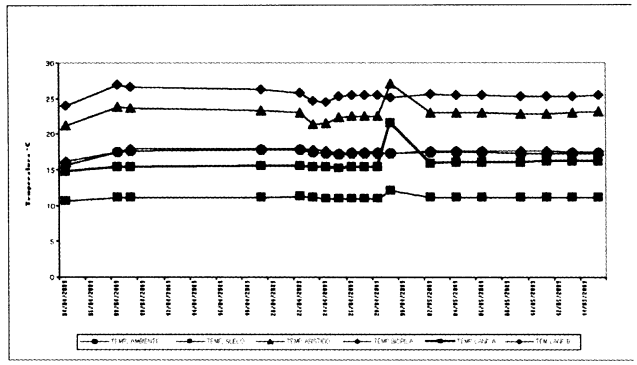
Graph 3 shows that the temperature levels change as expected with the different methods. The biocell having the highest average and the Landfarming B cell with the one meter membrane the lowest.

4. TPH reduction

Although the total number of microorganisms in the final assisted landfarming cell was one of the lowest, their effectiveness in reducing TPH was the highest. This is reflected in Graph 4 where the TPH fell to below 5,000 ppm within a month.

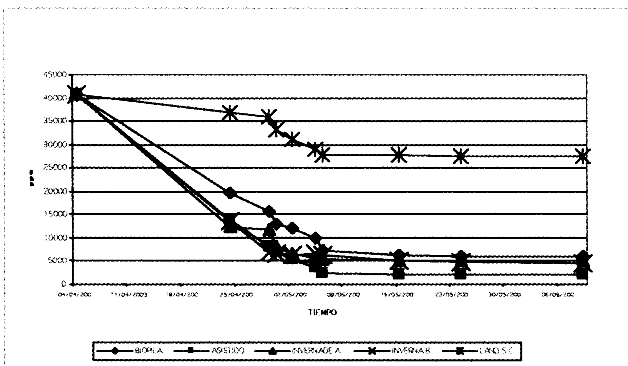


GRAPH 2. AVERAGE VARIATION OF TEMPERATURE



GRAPH 3. AVERAGE VARIATION OF TEMPERATURE

The concentration of TPH in all cell as a function of time diminished drastically reaching permissible levels at the end of approximately one month. The Biocell, however, showed slightly slower degradation than the other cells. In the control cell the natural attenuation of TPH concentration only reached 28,000 ppm in the same time period.



GRAPH 4. VARIATION OF TPH WITH TIME

CONCLUSIONS

This research demonstrates that, despite conditions of high altitude and extreme temperature gradients, it is possible to maintain the necessary number of microorganisms for effective hydrocarbon biodegradation in soils. In the Biocell, the number of microorganisms was enhanced to a high level during the treatment. The number of microorganisms in the other treatments was evaluated and used to establish the control parameters of humidity and temperature needed to maintain the levels needed to degrade the hydrocarbons. Thus it was found to be possible to carry out bioremediation in extreme conditions of temperature and high altitude through the formation of a microclimate using relatively inexpensive techniques.

Normal landfarming was very slow and did not reduce TPH concentrations to the target (required) level in the test period. Assisted techniques were very effective and low cost. The presence of OMA's according to the existing analitical data[5] should have been the most effective treatment. The addition of natural polysilicates (these are elements that can be found in a free state in the natural environment and do not cause any damage to the environment) proved that even in extreme temperature and altitude conditions biodegration to acceptable TPH levels was seen in short periods of time.

In landfarming systems with temperature control comparing the increment curve of the microbial activity that is represented by the count of microorganisms with the evolution curve of the decrease in content of hydrocarbons, shows a slight decrease in the beginning before the microorganism adapts to the medium. This occurs without interrupting the downgrading of TPH. Data indicate the microorganisms adapt appropriately approximately on the sixth day where the count is duplicated and we see a considerable decrease of hydrocarbons.

In the altiplano the biodegradation occurred mainly during assisted landfarming with polysilicates.

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