

DRAFT “OLAVARRIA LANDFILL GAS RECOVERY”

**FOR
CASE STUDIES
OF
CDM - LANDFILL GAS PROJECTS**

**PRESENTED AT A
WORKSHOP
IN
THE WORLD BANK
19TH APRIL 2007**

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1. BACKGROUND

1.1. General background

The Olavarría's municipal landfill has a property of 34 hectares and the projection of total waste disposal capacity is approximately of 35 years. The current sanitary landfill has been in operation since November 1999 and is owned by the Municipality of Olavarría.

The landfill is projected and organized in six independent cells to deposit urban solid residuals that will be used to capture the landfill gas (LFG) as soon as the new cells allow it. At present time it is not able for the landfill gas to be recovered in cell N° 1 and one is working in the disposition of the waste of cell N° 2. Each cell has 120 meters wide, 220 meters long with a maximum height of 12 meters. For the disposition of residuals it is carried into an excavation where it prepares a first clay layer and then is placed a membrane of PVC of 800 microns of thickness. For gathering the leachate it possesses a central PVC pipe with discharge for graviness to an underground tank and from there it is pumped to the leachate collection pond. In the cells are placed vertical tubes in a passive form until the landfill gas plant begins to capture LFG. The basic principle operation is to generate vacuum with the purpose of extracting the waste of the mass of residuals.

The LFG plant is compound for four basic components:

- System of extraction: wells and pipe of transport
- Suction plant and treatment of the LFG
- Combustion system and control system
- Leachate system

The wells of extraction of the LFG were installed along the perimeter and in the center of the cell. A net of main pipes were connected through control bolsters to secondary pipe distributed over the cell. The transport of the LFG from the pipes to the unit treatment was carried by blowers (regenerative turbines). The LFG suction equipment included pipelines header system and blowers. A pipeline header system conveys the flow of collected LFG from the well system facility to the blower. The blowers were installed with two regenerative turbines (stage centrifugal type). The LFG unit treatment consists in a condensate system. A knockout vessel was used to remove the condensate LFG. To combustion system was installed a burn of LFG (closed flare) in a controlled environment to destroy methane and other harmful constituents and discharge them safely to the atmosphere. The control system was used to measure the actual LFG flow and composition to avoid the intrusion of ambient air into the extraction wells and there by optimize the extraction of gas. In the first stage of this project, the LFG is captured and burnt without carrying out energy recovery. However, the use of LFG will be analyzed in function of the rate of real recovery of LFG that will be reached and by other economic factors. The present operation of the LFG Plant understands the application of the instructions given in the Monitoring Plan (MP) executing all the activities related to the implementation of the procedures given in the Operational Manual. The main responsibilities of the operator are related to:

- Data handling: maintaining an adequate system for collecting, recording and storing data according to the protocols determined in the MP, checking data quality, collection and record keeping procedures regularly.
- Reporting: preparing periodic reports that include emission reductions generated and observations regarding MP procedures.

- Training: assuring personnel training regarding the performance of the project activities and the MP.
- Quality control and quality assurance: complying with quality control and quality assurance procedures to facilitate periodical audits and verification.
- An Operational Manual to be elaborated by the project developer which include procedures for training, capacity building, proper handling and maintenance of equipment, emergency plans and work safety.

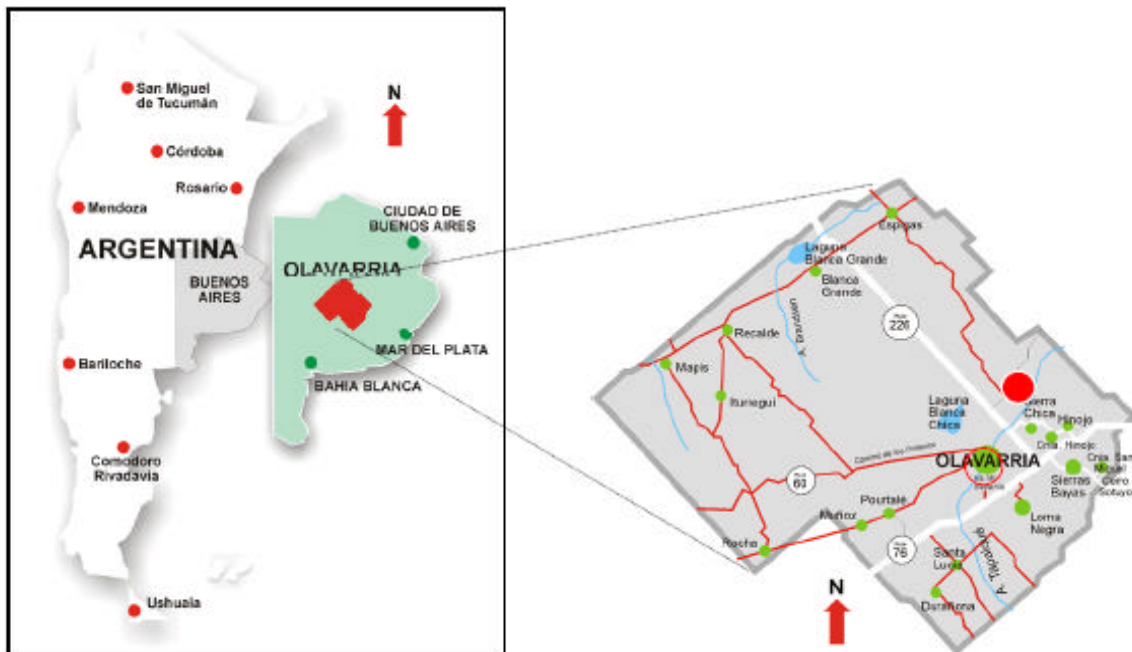
2. SITE INFORMATION

2.1. Data for Area

City	Olavarria
Name of the landfills	Olavarria Municipal Landfill
Site geology (sand, clay, etc.)	clay
Groundwater over/beneath bottom	groundwater beneath bottom
Precipitation (mm rain water)	1028 mm
Normal range of temp. Win./Sum. ($^{\circ}$ C)	6,9 $^{\circ}$C (Win.) / 21 $^{\circ}$C (Sum.)

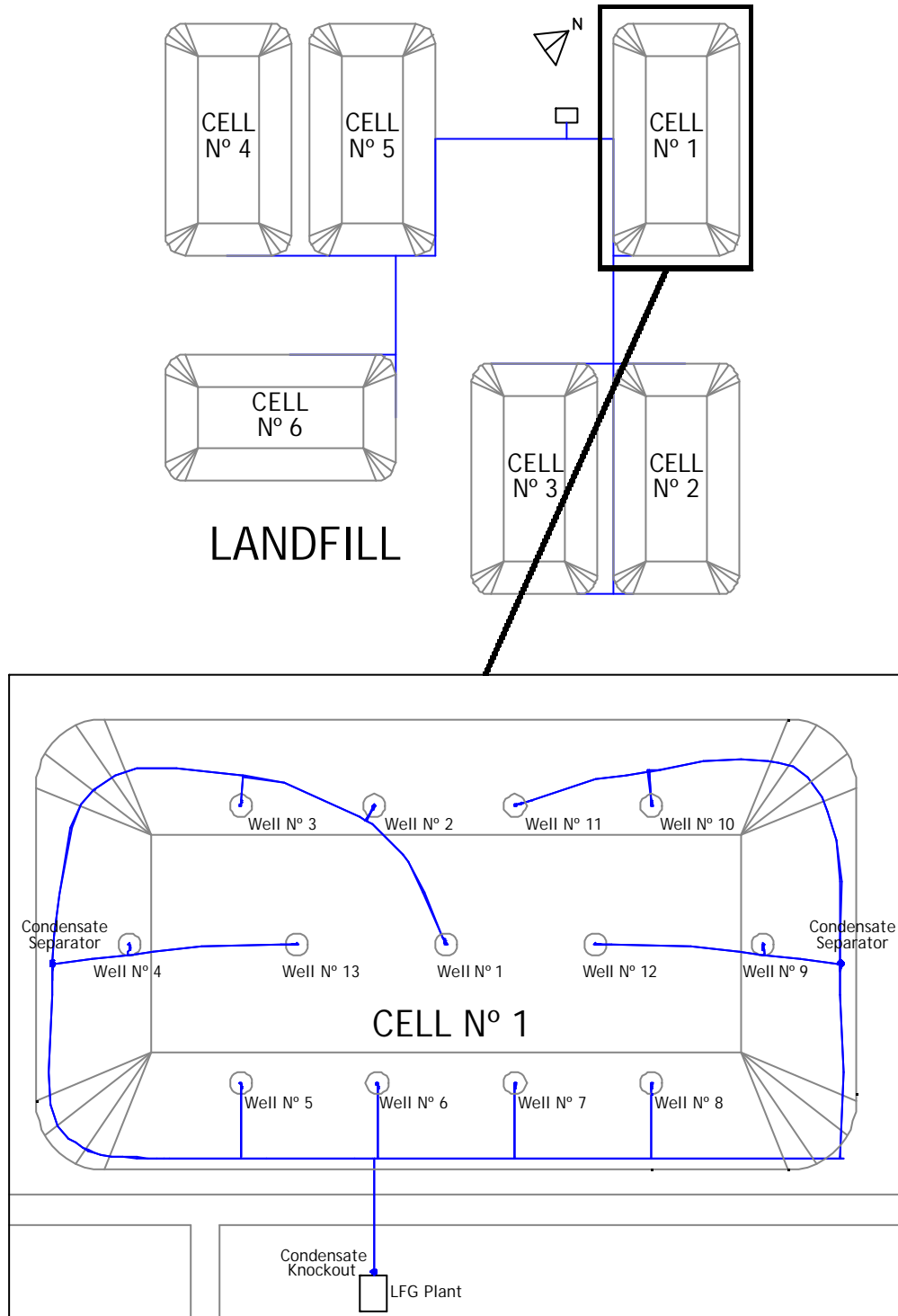
Table 1: Site area information

The Olavarría's municipal landfill is located at 9 km from the center of the town. The town of Olavarría has a population of 100,000 and is located at the center of Buenos Aires Province, 360 km from Argentina's capital, the city of Buenos Aires (see Figure 1). Approximately 180,000 tons of municipal solid waste (MSW) were disposed in the first cell that was recently closed. In March 2005 the second cell was opened for the disposition of MSW.



The current access to the landfill site is a gravel road in fairly good conditions. The landfill site is connected to the main electrical grid but not to the natural gas distribution

network. The landfill has been designed and constructed under sanitary engineering rules. According to previous hydro-geological studies, the site was selected in order to prevent groundwater contamination. The landfill has been insulated using a low permeability soil along with a synthetic liner. It has a leachate treatment system that include a stabilization pond and recirculation pumps and piping.



The municipal landfill is being operated by a private concessionaire supervised by the Department of Public Works of the Municipality of Olavarría.

2.2. Landfill construction

Start of landfill (Year)	1999
Closing of landfill (Year/year expected)	35 year from 1999
Area designated for landfilling (ha)	34
Site capacity at closure (Thousands tons)	715
Area used in 2006 (ha)	4
Max./min. depth of landfill 2006 (m.)	12 / 6
Average depth of landfill 2006 (m.)	8
Waste in place 2006 (Thousands Tons)	31.96
Gas extraction in 2006 from (Thousands m ³)	3.408
Annual waste quantity (1,000 tons)	42.78
Leachate drainage system (yes/no)	yes
Type of membrane in the bottom (if any)	PVC 800 microns

Table 2: Site construction data

2.3. Waste data

Year	MSW (ton)	Industrial/ commercial (ton)	Other (ton)	Total (ton)
1999	10 368			10 368
2000	38 012			38 012
2001	36 394			36 394
2002	29 174			29 174
2003	29 174			29 174
2004	31 777			31 777
2005	31 187			31 187
2006	31 906			31 906
Total:	237 992			237 992

Table 3: Amount of waste disposed of.

Type of waste	Waste composition (% by weight)
Domestic	58
Industrial, Commercial & Institutional	15
Construction	12
Garden waste	4
Other	11
Total:	100
Total organic (if this is available)	19

Table 4: Waste composition

2.4. Landfill operation

The existing municipal solid waste management in Olavarría consists basically in urban solid waste collection, disposal in the landfill, compaction and weekly cover, leachate collection and treatment, and the release of the LFG to the atmosphere through vent ducts without any treatment.

The leachate collection system possesses a central pipe of PVC that discharge by graviness to an underground tank and then is pumped to the leachate collection pond.

Usage of compactor (yes/no)	yes
Number of compactors	one
Is temporary cover used (yes/no)	yes
Frequency of temporary cover	weekly
Existence of final cover (yes/no)	yes
Type and thickness of final cover	rough, organic earth
Leachate collection from the bottom (yes/no)	yes
Leachate collection from trenches (yes/no)	yes

Table 5: Landfill operation

3. ESTIMATION OF LANDFILL GAS

3.1. Gas Model

The potential of generation of LFG of the Olavarría's municipal landfill was considered through the method of Canyon Scholl that is based on a kinetics of decomposition of the waste of first order (FOD)

This model uses the rate of generation of waste, the potential of methane generation (L_o) and the rate of decomposition (k) to estimate the potential of generation of LFG. The first value was obtained by accumulated registration of waste from the beginning of the operation of the landfill. The value of (L_o) it was considered starting by the formulates that were given by the Intergovernmental Panel for Climate Change (IPCC) considering the composition of the waste of Olavarría and a value of 102 cubic meters was obtained by ton of waste. For the value of (k) it was considered a half life for the degradability of the seven year-old residuals and using the expression given by the IPCC a 0.099 year^{-1} value.

According to the FOD model, the formula used to estimate the total methane generated within the boundary of the project in a given as follows:

$$CH_4 = \sum_x A \cdot k \cdot MSW_T(x) \cdot L_o \cdot e^{-k \cdot (y-x)}$$

where:

$CH_{4,y}$ = total methane generated at the landfill in year y [$\text{m}^3 \text{ CH}_4/\text{year}$]

A = normalization factor $[1-\exp(-k)]/k$

y = year of inventory

x = years for which input data should be added

k = methane generation rate [year^{-1}]

$MSW_T(x)$ = total municipal waste disposed at the landfill in year x [ton MSW/year]

L_o = methane generation potential [$\text{m}^3 \text{CH}_4/\text{ton MSW}$]

The methane generation potential L_o was calculated as follows:

$$L_o = MCF \cdot DOC \cdot DOC_F \cdot F \cdot \frac{16}{12}$$

where:

MCF = methane correction factor

DOC = degradable organic carbon in [ton C/ton MSW]

DOC_F = fraction of DOC dissimilated

w_{CH_4} = fraction by volume of CH_4 in landfill gas [$\text{m}^3 \text{CH}_4/\text{m}^3 \text{LFG}$]

16/12 = conversion from carbon to CH_4 [ton $\text{CH}_4/\text{ton Carbon}$]

IPCC (1996) gives default values for MCF according to the site management. For this project $MCF = 0.8$ was assumed.

DOC is given by IPCC as a function of waste composition. Taking into account the waste composition in Olavarría, a value of $DOC = 0.175$ [ton C/ton MSW] was calculated.

For DOC_F , a value of 0.7 is assumed (IPCC, 1996).

w_{CH_4} was estimated based on waste composition and verified in the field. Calculations yielded a value of $w_{CH_4} = 0.52$ [$\text{m}^3 \text{CH}_4/\text{m}^3 \text{LFG}$].

Introducing these values in Equation above and considering the methane density of 0.678 kg/m^3 at 15°C and 101 kPa , calculations yield $L_o = 102$ [$\text{m}^3 \text{CH}_4/\text{ton MSW}$].

Total municipal solid waste disposed in a given year $MSWT_{(x)}$ is known from records archived since the beginning of the landfill operations in November 1999. In order to estimate a projection of the $MSWT_{(x)}$ for future years, the projected growth of Argentina's GDP of 6% per year for the next years was taking into account. Then, to define the baseline scenario, a MSW generation growth rate of 2% was assumed for the years of the project (2006-2026). Thus, the annual average of the municipal solid waste disposed at the landfill during the 21-year crediting period is 42,780 ton/year. Table 3 shows the disposal of MSW at Olavarría's landfill since the beginning of the activity in 1999 and the projected MSW generation rate. The methane generation rate k was estimated using the formula given by IPCC (1996). k is related to the time taken for the DOC in waste to decay to half its initial mass (the half-life or $t_{1/2}$) as follows:

$$k = \frac{\ln(2)}{t_{1/2}}$$

For this project and following IPCC's recommendations, a DOC half-life of 7 years was assumed considering both the high moisture conditions in Olavarría (annual precipitations higher than 1000 mm) and the large amount of rapidly degradable material in the waste (almost 70%). This half-life yields a value of $k = 0.099 \text{ year}^{-1}$.

As a result of applying the First Order Decay model, an average of 60 cubic meters per hour of LFG would be released to the atmosphere through the passive vent system and landfill cover during the 21 year starting in 2006. This estimated value corresponds to 40,138 ton $\text{CO}_2\text{e}/\text{year}$ and represents the baseline emissions. Table 6 shows the estimation of LFG production.

3.2. LFG estimation

Year	Estimation of LFG production (1.000 Nm ³ /year)	Estimation of LFG extraction (1.000 Nm ³ /year)	Estimation of LFG extraction (Nm ³ /hour)
1999	1.717		
2000	4.636		
2001	4.778		
2002	5.297		
2003	5.616		
2004	6.232		
2005	6.700		
2006	6.834	3.408	330
2007	6.971	3.476	337
2008	7.110	3.546	344
2009	7.252	3.616	350
2010	7.397	3.689	357
2011	7.545	3.763	365
2012	7.696	3.838	372

Table 6: Estimation of LFG production and extraction

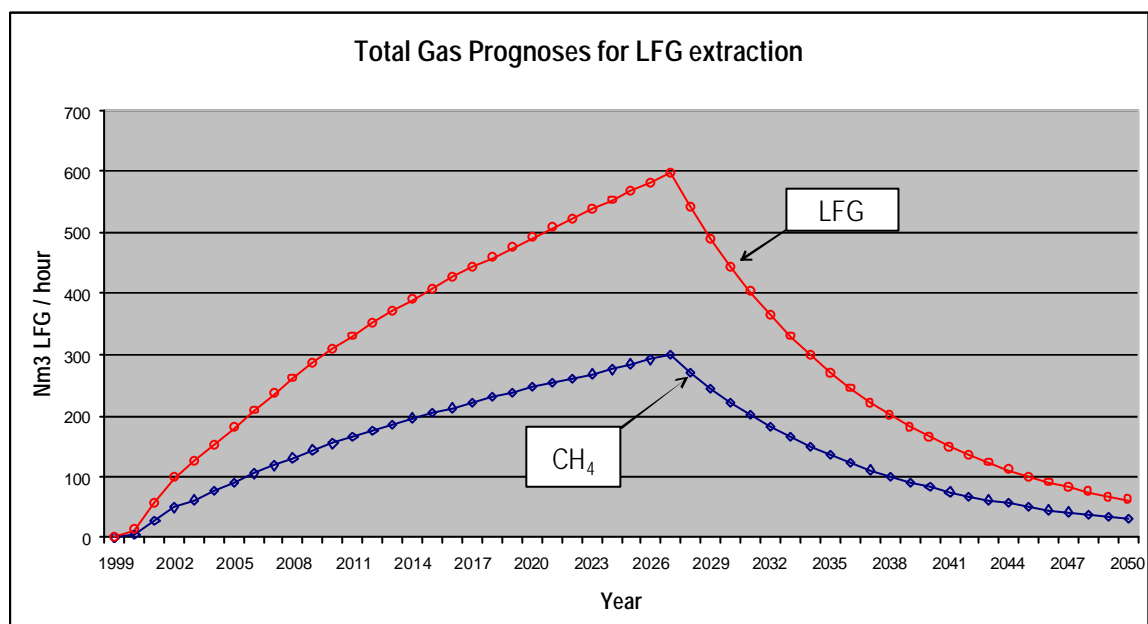


Figure 1: Estimation for gas extraction

4. TEST PUMPING

Pump capacity (m ³ /h)	312
Number of test wells	13
Duration of the test pumping	1 hour
Gas extraction from well no.1 (m ³ /h)	15.6
Gas extraction from well no.2 (m ³ /h)	17.4
Gas extraction from well no.3 (m ³ /h)	3.3
Gas extraction from well no.4 (m ³ /h)	4.2
Gas extraction from well no.5 (m ³ /h)	11.4
Gas extraction from well no.6 (m ³ /h)	10.5
Gas extraction from well no.7 (m ³ /h)	18.6
Gas extraction from well no.8 (m ³ /h)	10.8
Gas extraction from well no.9 (m ³ /h)	12.0
Gas extraction from well no.10 (m ³ /h)	5.1
Gas extraction from well no.11 (m ³ /h)	12.6
Gas extraction from well no.12 (m ³ /h)	21.9
Gas extraction from well no.13 (m ³ /h)	22.2
Total gas extraction (m ³ /h)	165.6

Table 7: Data and results from the test pumping

Well No	CH ₄ %	CO ₂ %	O ₂ %	N ₂ %
1	30.0	21.4	7.2	---
2	26.0	23.3	4.9	---
3	6.3	5.7	15.7	---
4	17.0	18.5	6.9	---
5	24.0	18.1	8.6	---
6	27.0	18.1	10.3	---
7	40.0	29.1	4.7	---
8	29.0	21.7	8.8	---
9	24.0	17.5	10.0	---
10	15.5	22.8	9.3	---
11	23.0	22.3	6.4	---
12	39.0	27.2	6.1	---
13	34.0	24.4	5.3	---
Total	25.8	20.8	8.0	---

Table 8: LFG composition from test pumping

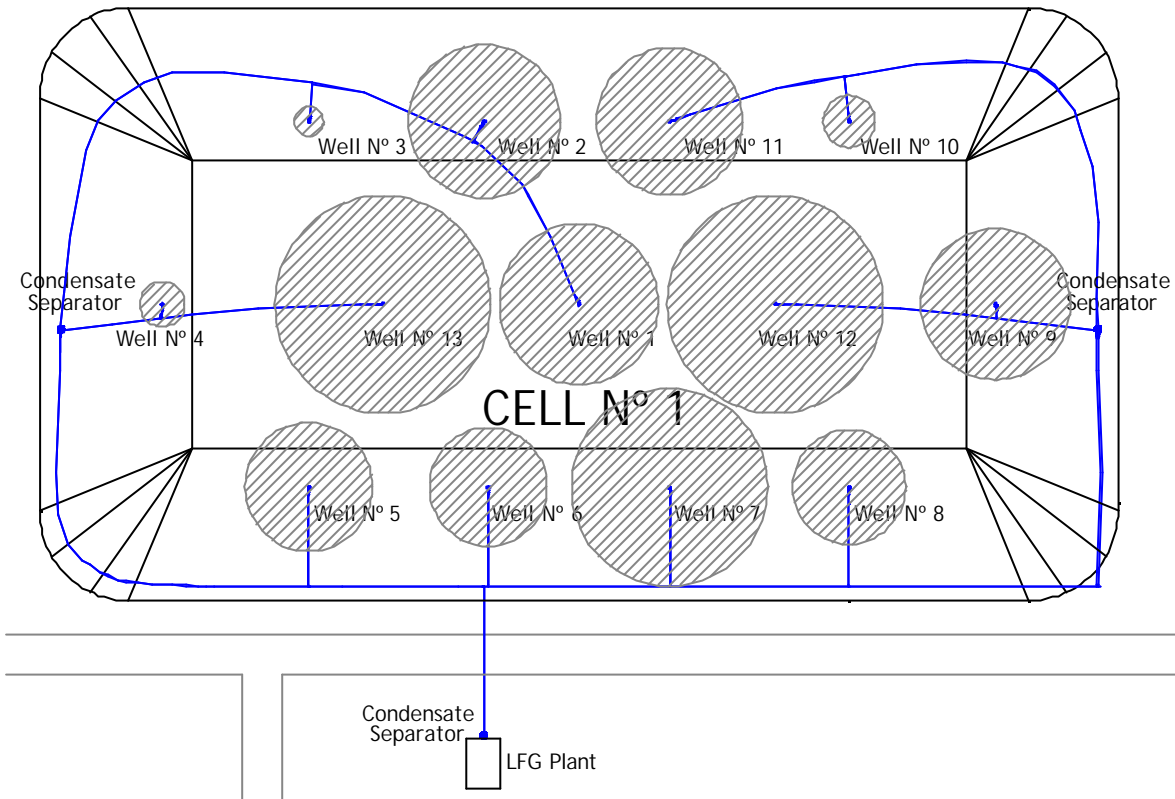


Figure 2: Zone of influence of wells

The results of the tests pumping indicated that some wells presented difficulties due to the high permeability (for lower compaction), due to this it was necessary to regulate each well to decrease the flow. The tests pumping result comparable with the result of the model indicated areas of influences smaller than they were defined for the model.

5. REAL LFG EXTRACTION

5.1. Estimated LFG extracted compared with real extracted

Year	Estimation of LFG extraction (1.000 Nm ³ /year)	Real LFG extraction (1.000 Nm ³ /year)	Difference (+/- 1.000 Nm ³ /year)	Difference (+/- %)
2006	3.408	282	- 3.126	- 91 %

Table 9: Estimation of LFG production and extraction
Values corresponding to five months

The specified value of 282.000 m³ is referred to a initial five months because previously it was in phase of plant test (suction adjustment in the wells for problems of infiltration air on the whole surface of the cell) and the reports during this time were not kept in mind.

5.2. Estimated LFG composition compared with real composition

Year	Estimated gas quality				Real gas quality			
	CH ₄ %	CO ₂ %	O ₂ %	N ₂ %	CH ₄ %	CO ₂ %	O ₂ %	N ₂ %
2006	50 %	---	---	---	29.2	---	---	---
Actual	---	---	---	---	31.3	---	---	---

Table 10: Estimation of LFG production and extraction

6. LANDFILL GAS PLANT

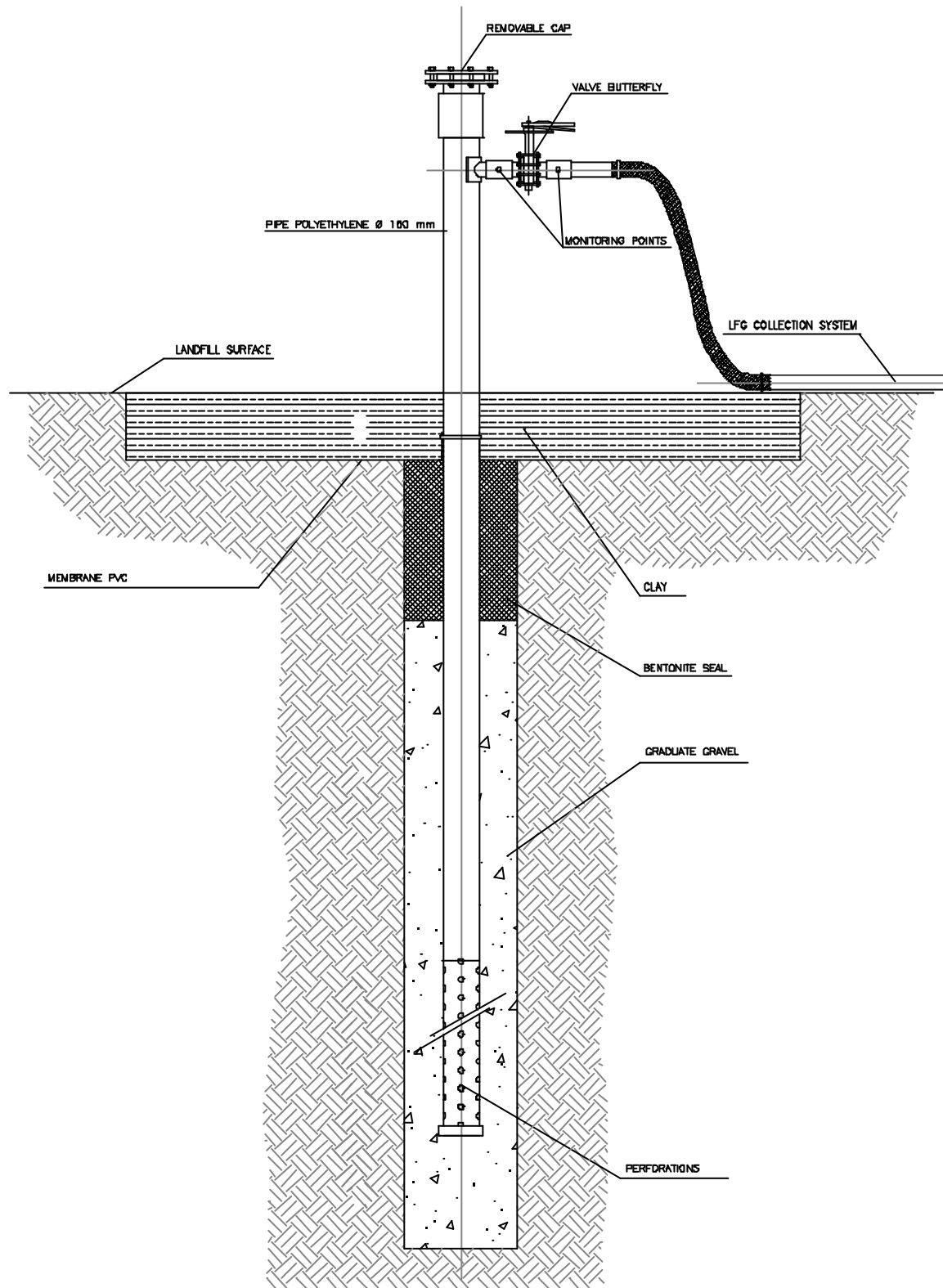
6.1. LFG Collection System

WELLS CONSTRUCTION

The perforations were carried out by means of the vertical drilling method for waste extraction, being 0.50 m the diameter of the extraction well. Inside the well a tube of high density polyethylene (Ø 160 mm) was placed with a variable length according the depth of the extraction well. A distance of 0.50 m was left between the bottom of the well and the end of the tube. The tube was perforated in such way to allow the LFG to go into of the extraction pipe. Around the tube was placed graduate gravel with a suitable size for this case. The superior part of the well was sealed with bentonite and then was recovered with a polyethylene membrane and with a superior covering of clay. At the top of well a pipe was built in a superior flange cap (which completes the function of inspection of the tube and extraction of the leachate when it needs to be carried out) and a butterfly valve that allows to regulate the contribution of flow of each well extraction in particular. From both sides of the butterfly valve were placed latchkeys for taking monitoring points and the measuring vacuum generated by the suction plant. The connection between this bolster and the LFG transport system is made by a flexible hose to the pipe of Ø 63 mm.

Wells	
Number of wells	13
Depth of wells/average depth (m)	6.50
Diameter of well (mm)	500
Diameter of gas extraction pipe (mm)	160
Distance between wells (m)	40
Presence of water/condensate in wells (yes/no)	Yes
Water/condensate pump in wells (yes/no)	Yes

Table 11: LFG Collection system



HORIZONTAL COLLECTION SYSTEM CONSTRUCTION

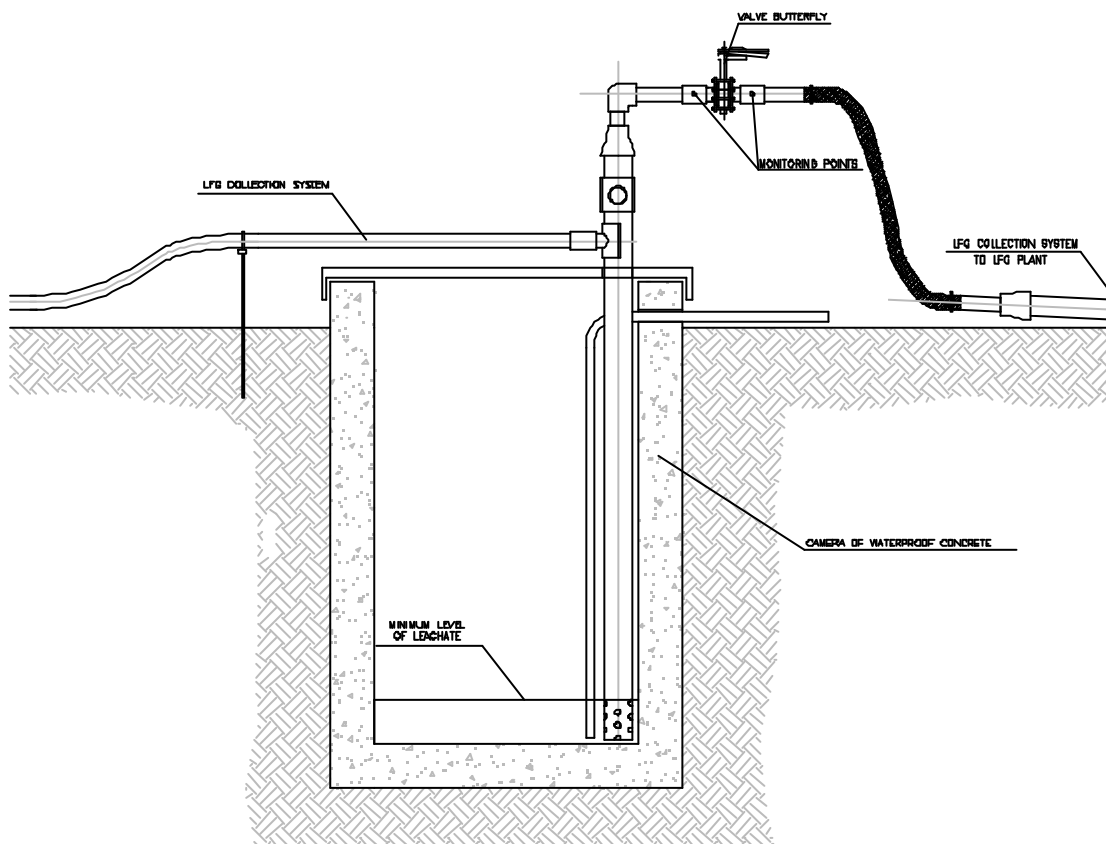
The disposition of the transport pipes as well as the collector of the extraction wells were made of high density polyethylene pipes of diameter 63 mm, 90 mm and 125 mm. The interconnection between the pipe collector that it comes from the bolster of the extraction well of Ø 63 mm. was made of a high volume valve linked by an electrofusion system. The section changes were made by polyethylene coupler of different diameters. In the superior extreme of cell N° 1 was let a polyethylene cap (Ø 125 mm.) for a future interconnection of the remaining cell.

Horizontal gas collection system (from wells to gas pump)	
Diameter of horizontal collection system (mm)	63 / 90 / 125
Condensate trap at low points (yes/no)	Yes

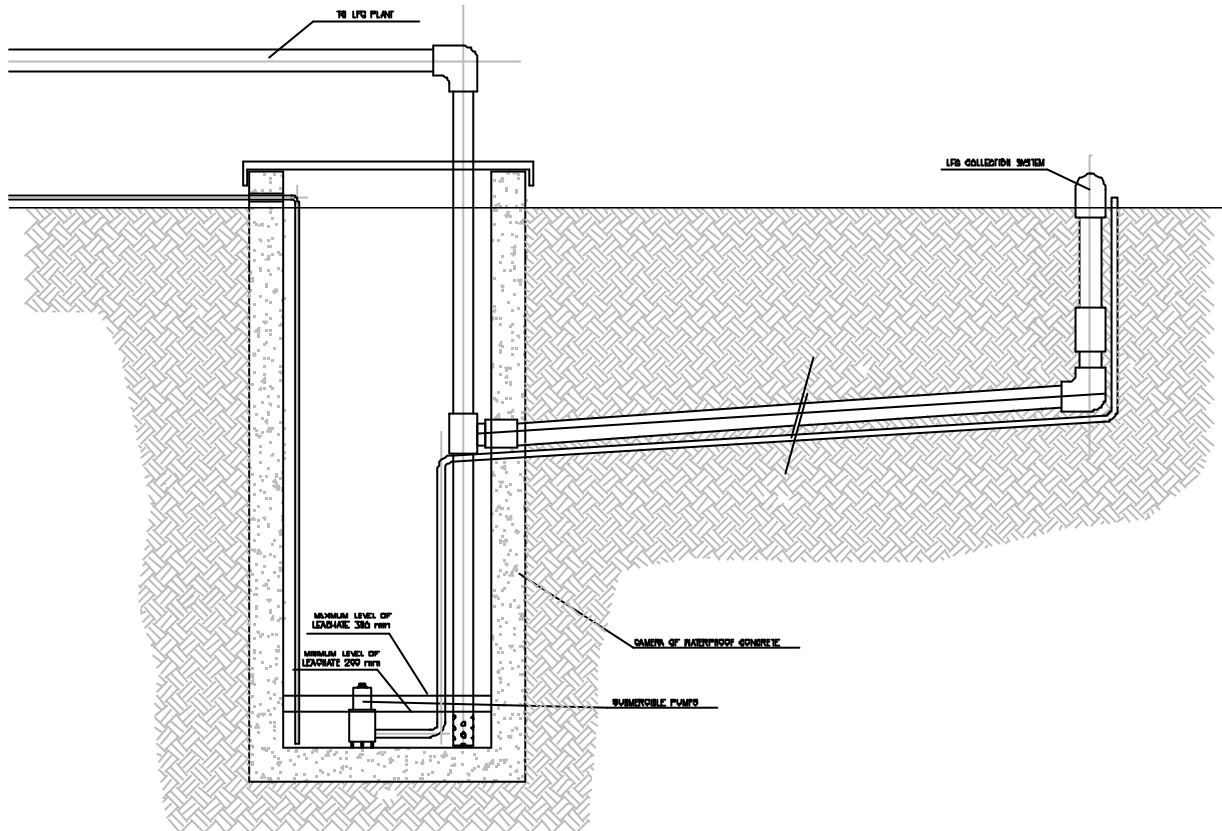
Table 11: LFG Collection system

SYSTEM LEACHATE COLLECTION SYSTEM CONSTRUCTION

The removal condensed system consists in a transport pipe of having leachate and three condensed trap. The transport pipe of having leachate begins in the condensed traps and it arrives at the existent the leachate collection pond next to the cell N° 1. This pipe is the polyethylene and its disposition is underground. The condensed traps are three. One is at end of the pipe line and the others are in the middle point of the LFG principal collector distribution pipe. This condensed trap was built in concrete and inside it is connected an automatic submersible pump.



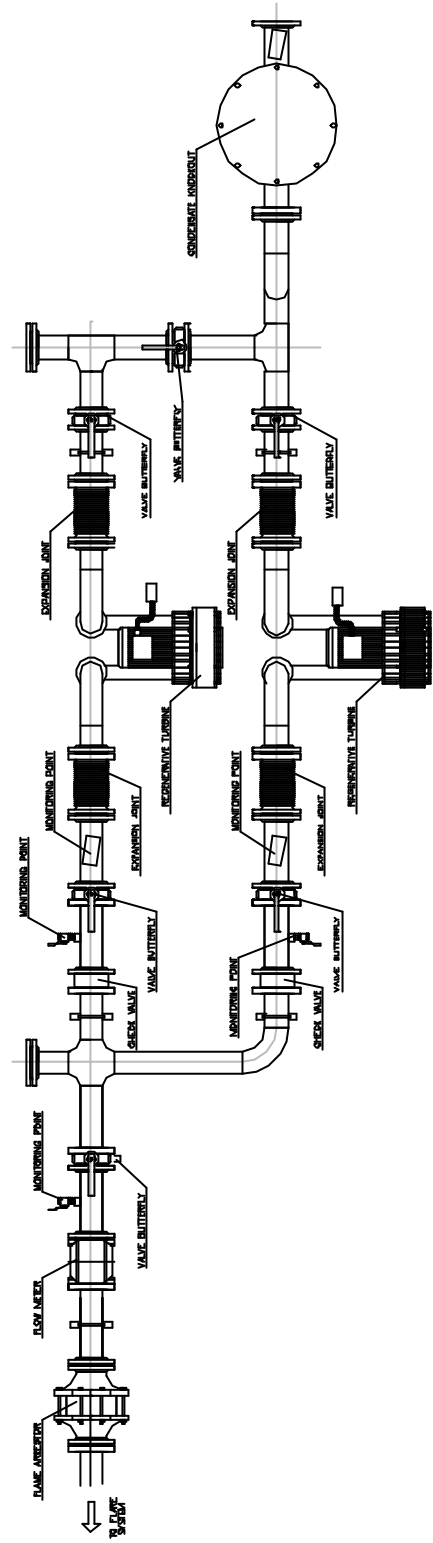
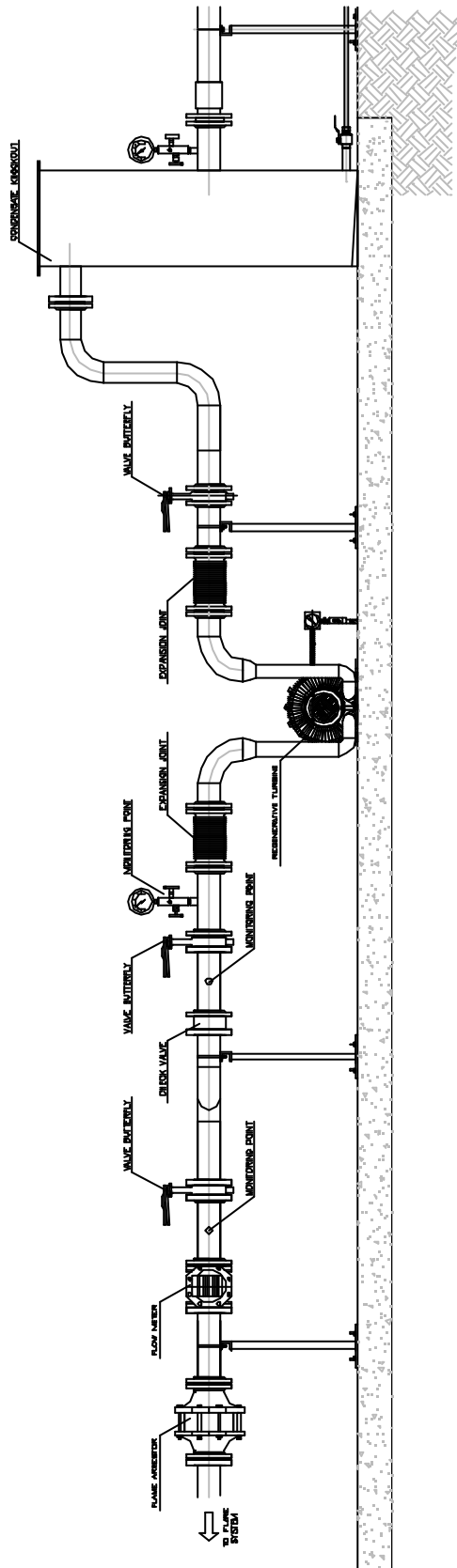
This pump transports the leachate captured to the leachate collection pond with an automatically levels system. In each condensed trap there is a polyethylene tube ($\text{\O} 125 \text{ mm.}$) which is placed in a vertical form. At both ways of the condensed trap is connected the polyethylene pipe ($\text{\O} 90 \text{ mm.}$) that enters to the condensed trap with a connection of clamp saddle polyethylene ($\text{\O} 90 \text{ mm.}$). This pipe has a suitable depth not to suction leachate and leave decant it in this condensed trap. In the superior part of this polyethylene tube ($\text{\O} 125 \text{ mm.}$) an elbow is placed for the horizontal exit of the suction system. This pipe contains a butterfly valve and a flexible hose that allows to give continuity to the LFG transport system



6.2. Gas Compressor/Pump System

Type of gas compressor/pump	Regenerative turbine
Capacity of gas compressor/pump (m^3/hour)	312
Suction pressure at the pump (mbar)	310
Suction pressure at the wells (mbar)	190

Table 12: Gas compressor/pump system



The LFG Plant has a condensate knockout made of galvanized steel that allows to extract the humidity contained in the previous LFG. The suction is carried by two regenerative turbine which could suction 312 m³/h causing a vacuum of 190 mbar. In the selection of the regenerative turbine it was considered the lost load into the transport system, the necessary minimum vacuum in the extraction wells and the exit pressure to flare system. The suction plant has two regenerative turbines of identical capacity (312 m³/h). At the entrance and at the exit of the regenerative turbines are placed expansion joints. Each pipe branch also has butterfly valves entrance and butterfly valves exit to control the flow. The regenerative turbines are commanded by a variator of speed which allows to adjust the vacuum in the suction line for optimize the LFG extraction of the wells.

The plant has a vacuumeter (previous to the regenerative turbines) to control the vacuum in the line. Also it has monitoring points (before the regenerative turbines) to control the pressure and the temperature. It has a flow meter gauged to measure the LFG quantity. The security condition, previous to the entrance of the gas to the train of valves of the burner, is to have a flame arrestor not to let the flame come back.

6.3. Utilization System

The system consist in a flare combustion with its automatisms that allow the mixture of air and LFG to proceed to the burn, by the following aspects:

- It has the capacity to operate with a variable methane concentrations of the LFG , between 30% and 70%.
- It assures the turbulent diffusion of the flame and the temperature between 950 °C and 1050 °C.
- The combustion efficiency in terms of the percentage of combusted methane is determined by the difference between the amount of captured methane in LFG (before flare) and the non-combusted methane (from the sampling ports in the flare).
- It guarantees an efficiency in the combustion of the methane upper to 97%.

Flare	
Type of Flare (open or closed)	Closed
Number of flares	1
Total capacity of flares (m ³ /h)	250
Actual gas used in flare (m ³ /h)	45

Table 13: LFG utilization system

6.4. Energy Production

Table 14: Annual Energy production

6.5. Operation of the LFG Plant

Is it possible to regulate the suction/flow from the individual wells and/or horizontal extraction pipes (yes/no)	yes
Are there any automatic regulation for the gas extraction (yes/no)	no
Is water/condensate from gas wells and/or horizontal extraction pipes removed (yes/no)	yes
Are there operation staff at the plant 24 hours/day	no
Do the alarm system call for attention 24 hours/day to the operator (yes/no)	yes
What is the plant efficiency (working hours/year)	6817 hours / year (77,82 %)

Table 15: Operation of the LFG Plant

During the operation of the LFG capture plant, two main problems are found:

- Waste compression: during the refilling, the waste compression was low and heterogenous. There was not a high compression grade, and the problem generated was the filtration of air in the cell borders. These filtration of air was partly corrected in some wells. A wider coverage in the well was done with a PVC 800 microns membrane , increasing the coverage surface. These block the air passes through the upper well surface . In this way, the well performance was greatly increased.
- Leachate: the leachate was increased by the water filtration during the rains, overpassing the gas extraction wells. These made the LFG extraction get blocked. These problem was solved when leveling the cells to let the water drain and automating the lixiviated pump, decreasing, in this way, the accepted liquid levels in the cells.

Operation of the plant: on January 2006, the LFG capture plant started with a flow of 80 m³/h and a 24% of CH₄ average. To solve the problem of air filtration , and the lixiviated liquid overpassing the gas extraction wells, it was decided to decrease the levels (between -7 and -10 Mbar) avoiding in this way, the filtration of air for the permeability of the covering, reaching a flow of 33 m³/h and 31% of CH₄.

This problem is being corrected increasing the waste compression in the cell N° 2 and in the rest of them. Also is being corrected the temporary and finally cover used in the cells. It let us arrive at values nearly of the estimation model of LFG prognoses capture. At present is improved the capture gas with a rate average of 40 m³/h of LFGs with an average concentration of CH₄ of 32%. It is expected that with the sow of grass in the superior part of the landfill diminishes the infiltration of air, that is main problem that it was not keep in mind in the model project.

6.6. Measuring and analyzing system

Are there stationary gas analyser in the plant (yes/no)	No
Which gases are analysed (CH ₄ , CO ₂ , O ₂ , H ₂ S, ?)	---
Type of portable gas analyser used	Portable gas analyzer GA 2000
Which gases are analysed (CH ₄ , CO ₂ , O ₂ , H ₂ S, ?)	CH₄, CO₂, O₂, CO, H₂S
How often is the gas analysed from the individual wells (daily, weekly, or ?)	weekly
Are pressure, temperature, etc. measured automatically or manual (a/m)	automatically

Table 16: Measuring and analyzing system

6.7. Consultant, Contractor and O&M employees

Consultant for implementation (good/poor)	good
Did the consultant have good references and long experience in LFG plants (approx. years)	four year
Contractor for implementation (good/poor)	good
Did the contractor have good references and long experience in LFG plants (approx. number of plants)	two
Did the team for start-up and running-in have expertise (yes/no)	no
Good training of O&M employees (yes/no)	yes
Good O&M manuals (yes/no)	yes

Table 17: Consultant, contractors and O&M employees

6.8. Economy

Year	Investment costs US\$	Annual income from energy US\$	Annual income from CO ₂ credit US\$	O&M costs US\$
2005	US\$ 124.196^(*)	---	---	---
2006	US\$ 360	---	US\$ 5.796^(**)	US\$ 18.585

Table 18: Economy

^(*) engineering and construction plan cost.

^(**) corresponding only a certification period.