USAID
FROM THE AMERICAN PEOPLE

ESTIMATING ENERGY POTENTIAL OF BIOGAS FROM AL AKEEDER LANDFILL

Final Report

September 17, 2009

This publication was produced for review by the United States Agency for International Development. It was prepared by Dr. Hani Abu-Qdais and JUST project team.

ESTIMATING ENERGY POTENTIAL OF BIOGAS FROM AL AKEEDER LANDFILL

Final Report

USAID JORDAN ECONOMIC DEVELOPMENT PROGRAM

DELOITTE CONSULTING LLP

USAID/JORDAN

USAID/ OFFICE OF ECONOMIC GROWTH (EG)

SEPTEMBER 17, 2009

AUTHOR: DR. HANI ABU-QDAIS AND JORDAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY PROJECT TEAM

DELIVERABLE NO: 5E.14.6.1.14.2T

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Al Akeeder landfill is the largest landfill site in Northern Jordan. The site serves more than 20 municipalities that comprise about 70 towns and villages and receives an average daily amount of 700 tones of solid waste. The site operation started in 1981. The only criteria used in the selection of the landfill site were low land cost and low population density within the vicinity of the site. Nowadays, the site is surrounded by several population centers. Due to the emissions generated from the site, Al Akeeder is considered as one of the hottest environmental spots with several adverse environmental impacts.

In support of a project that would reduce emissions generated by the second largest landfill in Jordan, USAID Jordan Economic Development Program (SABEQ) agreed to fund a project to estimates of the amount of biogas that can be recovered from the Al Akeeder landfill. The amount of the approved fund is 49,100 JD. To provide the necessary tools to design the project, Common Services Council (CSC) of Irbid Governorate – owners and operators of Al Akeeder – in association with Queen Rania Center for Environmental Science and Technology at Jordan University of Science and Technology (JUST) put the plan and implemented the funded project.

The project team that is composed of University professors, researchers and engineers estimated the quantity of generated landfill gas (LFG) and its energy potential from Al Akeeder landfill for possible control, collection and utilization. The project has investigated the possibility of implementing a gas collection system to extract the gas either to flare the gas or to fuel a power plant using internal combustion engine generator. To achieve that, a pilot biogas plant with two-test extraction biogas wells, vacuum pump and storage tank was constructed at the landfill site. As part of this investigation, several field tests and surveys were carried out to provide accurate and reliable information regarding the solid waste quantities and composition, as well as methane potential of the solid waste. In addition, some laboratory tests were conducted to estimate the methane production rate from individual waste components.

A road map for preparation of the project to be listed as a Clean Development Mechanism (CDM) project has been prepared. An application was submitted to The Designated National Authority (DNA) at the Ministry of Environment to list it as a CDM project. As a result, in 2008 Al Akeeder landfill has been considered a CDM project by the DNA. This has paved the road for putting Al Akeeder landfill on the international investment map, where several international firms expressed their willingness to invest in the landfill site.

2. INTRODUCTION AND BACKGROUND

Al Akeeder Landfill is located in Northern Jordan, near the main road from Irbid to Mafraq Governorate. It is 27 km to the east of Irbid city, within the Yarmouk Watershed. The site has coordinates of 251° 22' E and 216° 33' N, at a distance of 1 km from the international borders with Syria, as shown in Figure1. The nearest village is about 2 km to the southwest called Al Akeeder village. The solid waste disposal at the site started in 1981. The criteria used in the landfill site selection were the low population density and the low land cost. Al Akeeder landfill is the largest landfill in northern region and the second largest one in the country.

A study conducted in 1987 by Abu Qdais, reported that the method used for solid waste disposal was open combustion in place, followed by spreading. Solid waste was combusted in piles, after which the residues of combustion were removed and spread on the site. Nowadays, open burning process is banned.

Abu Qdais (1987) estimated the remaining useful life of the landfill is about 15 years (up to 2003). However, the CSC acquired further land and increased the landfill area from 10 hectares in 1981 to about 80 hectares as of today. This has given more space to dispose more solid waste, which continued up to date. Due to the increase in the area, the landfill is expected to serve up to the year 2020.

Despite the improvements that took place in the landfill operations, Al Akeeder is still considered as unsanitary landfill. It is one of the hottest environmental spots in Northern Jordan. Due to the absence of gas and leachate management and control systems, gases and leachate emissions from the landfill are major contributors to the atmosphere and groundwater contamination. The methane concentration below the landfill surface is sufficient to start a fire spontaneously, which is evident by the frequent fires that are taking place at the site

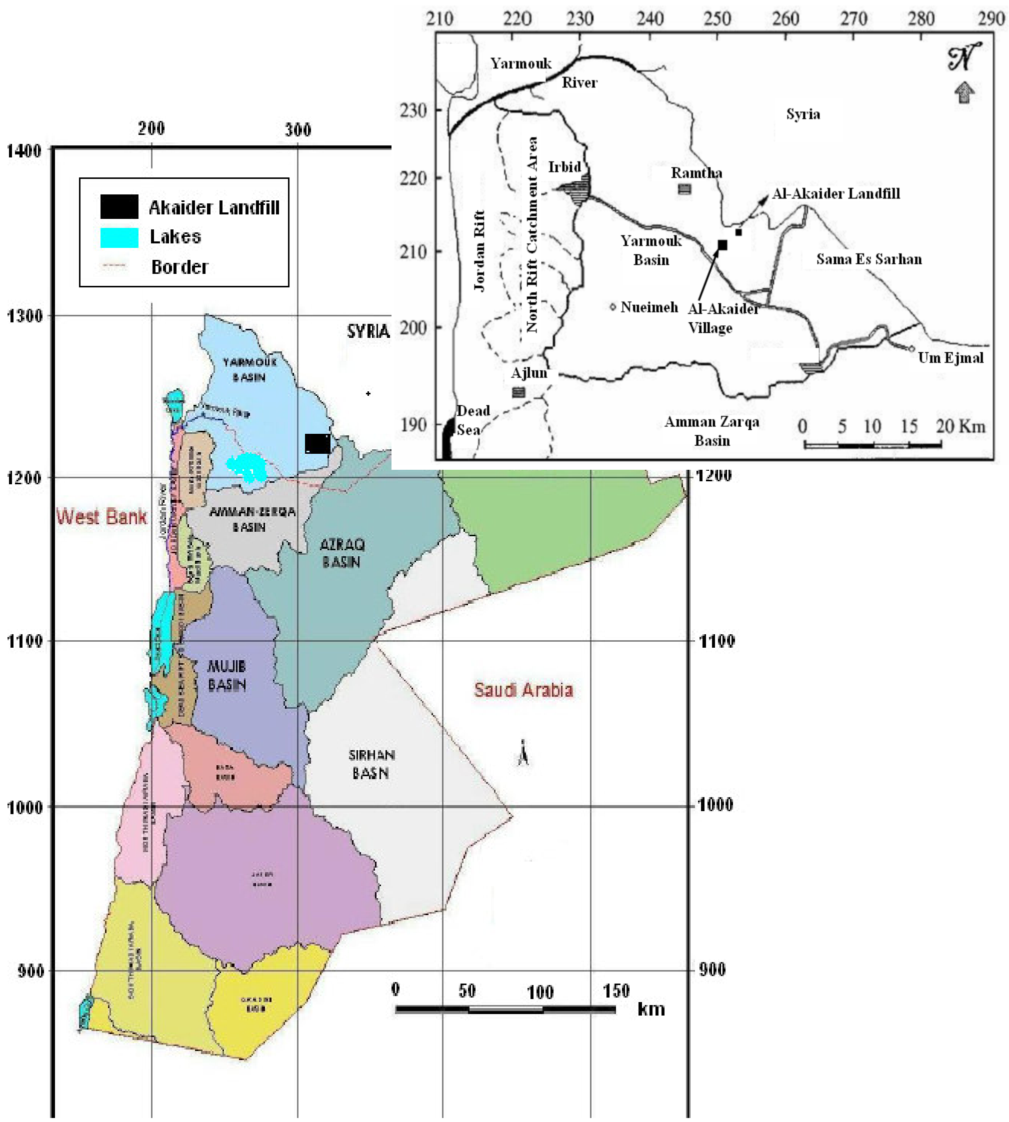

Figure 1: Location of Al-Akeeder Landfill

3. PROJECT AIM AND OBJECTIVES

The LFG industry has evolved over the past 20 years, accumulating substantial experience and knowledge. Unfortunately, in developing countries like Jordan, much of this knowledge and expertise has not yet developed to a level that permits proper and efficient utilization of such clean energy resource. The project is aiming at estimating the quantity of biogas generated from Al Akeeder landfill and its energy potential.

The specific objectives are:

Assess the amount of biogas that is generated for the development of an LFG control and management project at Al-Akeeder.

To quantify the potential greenhouse gas (GHG) emission reduction as a result of project implementation.

To provide tools that will assist the landfill owner in making informed decisions regarding investing in additional investigations or moving forward with a project at the landfill.

To put a road map towards considering the project as a CDM project.

By achieving the stated objectives, it was possible to provide general background information for the decision-makers and investors on quantity of biogas and its potential utilization. On the other hand, one of the important project outcomes is the project listing Al Akeeder landfill by the Designated National Authority (DNA) as a Clean Development Mechanism (CDM) Project.

4. BASIC SCREENING CRITERIA FOR AL AKEEDER BIOGAS PROJECT POTENTIAL

Determining if an energy recovery project may be the right option for a certain landfill is the first step in assessing the project options. In order to determine whether the project will likely to succeed at AL Akeeder landfill, the landfill has been subjected to initial screening criteria. The criteria were proposed by the United State Environmental Protection Agency (USEPA). Based on these criteria, it can be determined whether the landfill is a good candidate for energy recovery.

The proposed EPA criteria that are used as guiding ones are listed below:

- At least one million tons of waste in place
- Still receiving waste, or closed for not more than a few years
- Landfill depth of 12 m or more.

By applying the mentioned criteria to AL Akeeder landfill, the following can be concluded:

The amount of solid waste landfilled in the site since its operation in 1981 to date (2009) is greater than one million tons as shown from table 1

In addition, the site is still in operation, which implies the disposal of waste is still taking place at the site. As for the land filling depth, the investigation of the site conditions and information gained from the site operators indicate that the solid waste depth in the site is ranging from 15 to 30 m. This has been verified later by the excavated biogas testing wells, where two wells with depth of 22 and 30 m were excavated.

Based on the above facts, Al Akeeder landfill is meeting the screening criteria and considered a good candidate for energy recovery project.

Table 1: Annual quantities of solid waste disposed at AL Akeeder landfill

Yaer	Population	SW Quantity (ton)	
		0.91kg/cap/day	0.72 kg/cap/day
1981	552774	165243.4957	130742.1065
1982	572414	171114.5791	135387.3593
1983	592054	176985.6625	140032.6121
1984	611694	182856.7459	144677.8649
1985	631334	188727.8293	149323.1177
1986	650974	194598.9127	153968.3705
1987	670614	200469.9961	158613.6233
1988	690254	206341.0795	163258.8761
1989	709894	212212.1629	167904.1289
1990	729534	218083.2463	172549.3817
1991	749174	223954.3297	177194.6345
1992	768814	229825.4131	181839.8873
1993	788454	235696.4965	186485.1401
1994	808094	241567.5799	191130.3929
1995	827734	247438.6633	195775.6457
1996	849207	253857.6945	200854.4396
1997	870680	260276.7258	205933.2336
1998	892153	266695.7571	211012.0276
1999	915470	273666.0245	216526.9644
2000	921737	275539.4501	218009.2352
2001	944683	282398.8126	223436.4232
2002	969543	289830.3367	229316.3104
2003	994402	297261.5619	235195.961
2004	1023400	305930.079	242054.568
2005	1035102	309428.2164	244822.325
2006	1046804	312926.3537	247590.0821
2007	1058506	316424.4911	250357.8391
2008	1070208	319922.6285	253125.5962
2009	1081910	323420.7659	255893.3532
2010	1093612	326918.9032	258661.1102
2011	1105314	330417.0406	261428.8673
2012	1117016	333915.178	264196.6243
2013	1128718	337413.3153	266964.3814
2014	1140420	340911.4527	269732.1384
2015	1152122	344409.5901	272499.8954
2016	1163824	347907.7274	275267.6525
2017	1175526	351405.8648	278035.4095
2018	1187228	354904.0022	280803.1666
2019	1198930	358402.1396	283570.9236
2020	1210632	361900.2769	286338.6806

5. MODELING THE BIOGAS PRODUCTION FROM AL AKEEDER LANDFILL USING GAS-SIM

5.1 CONCEPT BEHIND GAS-SIM

The biodegradation of organic material is carried out by a multi-phase first order decay equation that deals with the three degradable fractions separately and aggregates the amount of carbon converted to LFG. The rates of decay and degradation half-lives are dependent on the waste moisture content; a wet waste will degrade at a faster rate than a dry one. The gas generation is determined using a multi-phase first order LFG generation equation, developed by the HELGA framework. The Gas-sim multi-phase equations can:

- Define the mix (breakdown), composition and moisture content of waste in the landfill site
- Calculate LFG generation based on the degradation rates of the individual materials in the land-filled waste.

These features make the Gas-Sim multi-phase equation highly flexible and allow it to be modified to individual landfill sites, taking account of specific waste streams, filling / deposition rates and environmental conditions.

The governing equations are:

$$C_t = C_o - \left[C_{o,1}e^{-k_1 t} + C_{o,2}e^{-k_2 t} + C_{o,2}e^{-k_3 t}\right] \quad \text{.............................. (1)}$$

$$C_x = C_t - C_{t-1} \quad \text{.............................. (2)}$$

Where;

C_t = Mass of degradable carbon degraded up to time t (Mg)

C_o = Mass of degradable carbon at time t = 0 (Mg)

$C_{o,1}$ = Mass of degradable carbon at time t = 0 in each fraction (1,2,3,rapidly, moderately & slowly) (Mg)

C_x = Mass of carbon degraded in year t (Mg)

t = Time between waste emplacement and LFG generation (yr)

k_i = Degradation rate constant for each fraction of degradable carbon (yr^{-1})

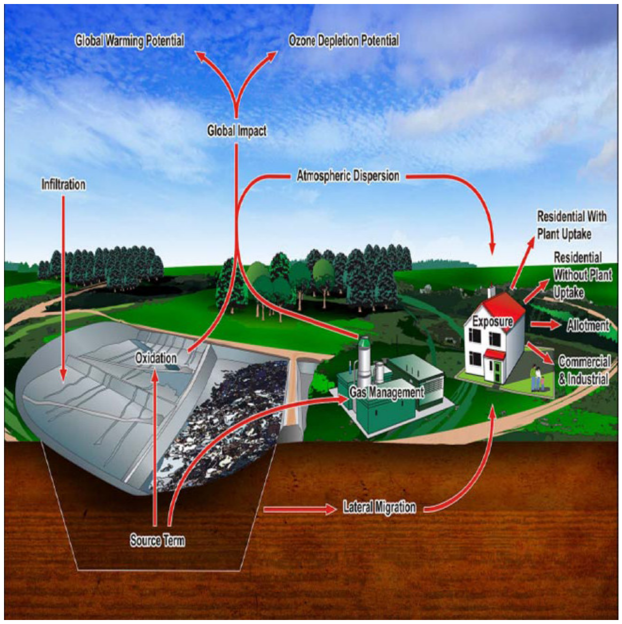

Figure 2: Landfill Emissions as considered by Gas Sim model **(Gas Sim Manual)**

5.2 DATA INPUT

Data required by Gas-Sim including solid waste data, landfill characteristics and climatic data are summarized in Table…

Table2: Data Required by Gas-Sim Model

Data Type	Parameter	Unit
Solid Waste Data	Quantity	Ton
	Composition	-
	Cellulose Decay Rates	$Year^{-1}$
	Moisture Content	%
	Waste Density	Ton / m^3
	Porosity	vol. / vol.
	Leachate Head	m
	Hydraulic Conductivity	m / sec
Landfill Characteristics and Soil Data	Landfill Area	m^2
	Soil Layer Thickness	m
	Hydraulic Conductivity	m / sec
Climatic Data	Rainfall	mm

5.3 LANDFILL GAS GENERATION OF AL AKEEDER LANDFILL

Landfill gas generation is simulated from 1981 to 2055. The trend of the simulation follows the triangular model. In the period from 1981 to 2021; the methane generation increases as well as the waste input quantities. After the year of 2021, the landfill is assumed to be reaching its full capacity and will be closed; hence the methane generation rate will decrease. This can be interpreted as: the landfill enters a stage of stabilization where methanogenic bacteria starts to produce less methane amounts due to low moisture content and low fresh biodegradable solid waste.

Since Gas-Sim input data is probabilistic, (the model accepts data as probability distribution or as a range). The most sensitive parameters of the Gas-Sim model are the cellulose decay rates. Since there is no calibration due to the lack of real measurements; the cellulose decay rates were obtained from previous studies (one of them were conducted on a Jordanian landfill) and fitted to a probability distribution before being entered to the software. Methane generation results for different confidence intervals (5 % to 95%) are outlined in Figure 3 .

Gas-Sim model is capable of simulation the methane production for 100 years. However, methane generation has been estimated to a period of 35 years after the closure of the facility. The waste input quantity for the study period was entered to the model as a range to account for the uncertainty.

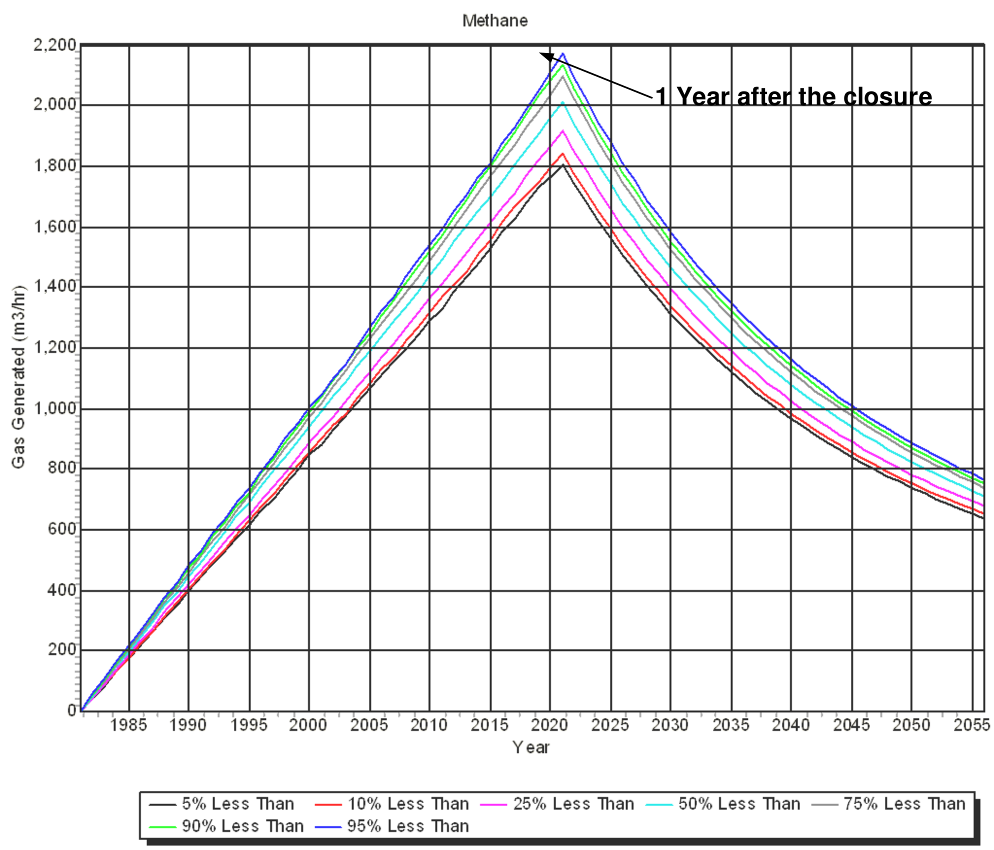

Figure 3: Gas-Sim Methane Generation Results (1981 – 2055)

As it can be seen from figure 3, the methane generation peak will be reached by the year 2021, one year after the landfill closure. The peak amount will range from 1800 m^3/hr to about 2170 m^3/hr.

6. GLOBAL WARMING POTENTIAL (GWP) OF AL AKEEDER LANDFILL

Gas-Sim determines the effect of green house gases and compares the effect of each compound to carbon dioxide. For example; methane has 21 times the effect of carbon dioxide. Table 3 shows the species contributing to GWP and their CO2 equivalence during the year 2008. It can be seen that the total GWP was 194247 tons of CO2 equivalent.

Table 3: GWP Species Emitted from Al-Akeeder Landfill, 2008

Species	GWP (tones of CO_2)
Methane	150000
Carbon Dioxide	23300
1, 1, 1, 2 – Tetrafluorochloroethane	2.88
1, 1, 1 – Trichlorotrifluoroethane	54.3
1 – Chloro – 1, 1 – difluoroethane	155
Chlorodifluoromethane	4570
Chloroform	0.221
Chlorotrifluoromethane	1280
Dichlorodifluoromethane	13600
Dichloromethane	3.77
Trichlorofluromethane	956
Trichlorotrifluoroethane	325
Total	**194247**

About 77% of the GWP of Al Akeeder is due to methane emissions, while 12% is due to carbon dioxide.

7. ESTIMATION OF POWER POTENTIAL

To estimate the potential of the landfill, two vertical extraction wells (referred to as Wells 1, 2) were drilled. Well 1 was installed at depth of 30m and well 2 was installed at depth of 22m. The horizontal distance between the two wells is 60 m. Figure 4 presents a typical detail of construction for the extraction wells.

The two wells were connected to an electrically powered mechanical blower, to exert a vacuum on the extraction wells and withdrawal LFG from the wells. Interconnection of the two extraction wells and the blower was with solid piping. The pipes inside the wells are 4 inches diameter with 10 mm randomly drilled holes to form LFG flow passage. The connecting pipes are 3 inched diameters. A portable diesel powered electrical generator powered the blower on-site. Flow control valves were installed at each extraction well as well as at the blower inlet to allow adjustment of vacuum and flow both system-wide and at individual wells. LFG was collected in 1 m stainless steel cylinder made especially for the purpose. The cylinder can resist high pressure, corrosion and erosion.

The project team hired four local contractors to implement the above work as follow:

- **Contractor A:** Driller to perform the drilling of the two extraction wells.
- **Contractor B:** To construct the piping system of the two extraction wells together with the connecting pipes and valves,.
- **Contractor C:** To implement the civil works like trenches for piping, bas of the plants and manholes for the well heads.
- **Contractor D:** A local workshop for electromechanical works of the plant was used for installing the blower, fabricating the storage tank, installing the burner and other steel works.

The purpose of installing the two extracting wells and the flaring system (Blower, storage tank and burner) is to:

- To measure the biogas composition from the landfill.
- To measure methane emission levels.
- Investigates the possibility of generating energy from the excavated wells.

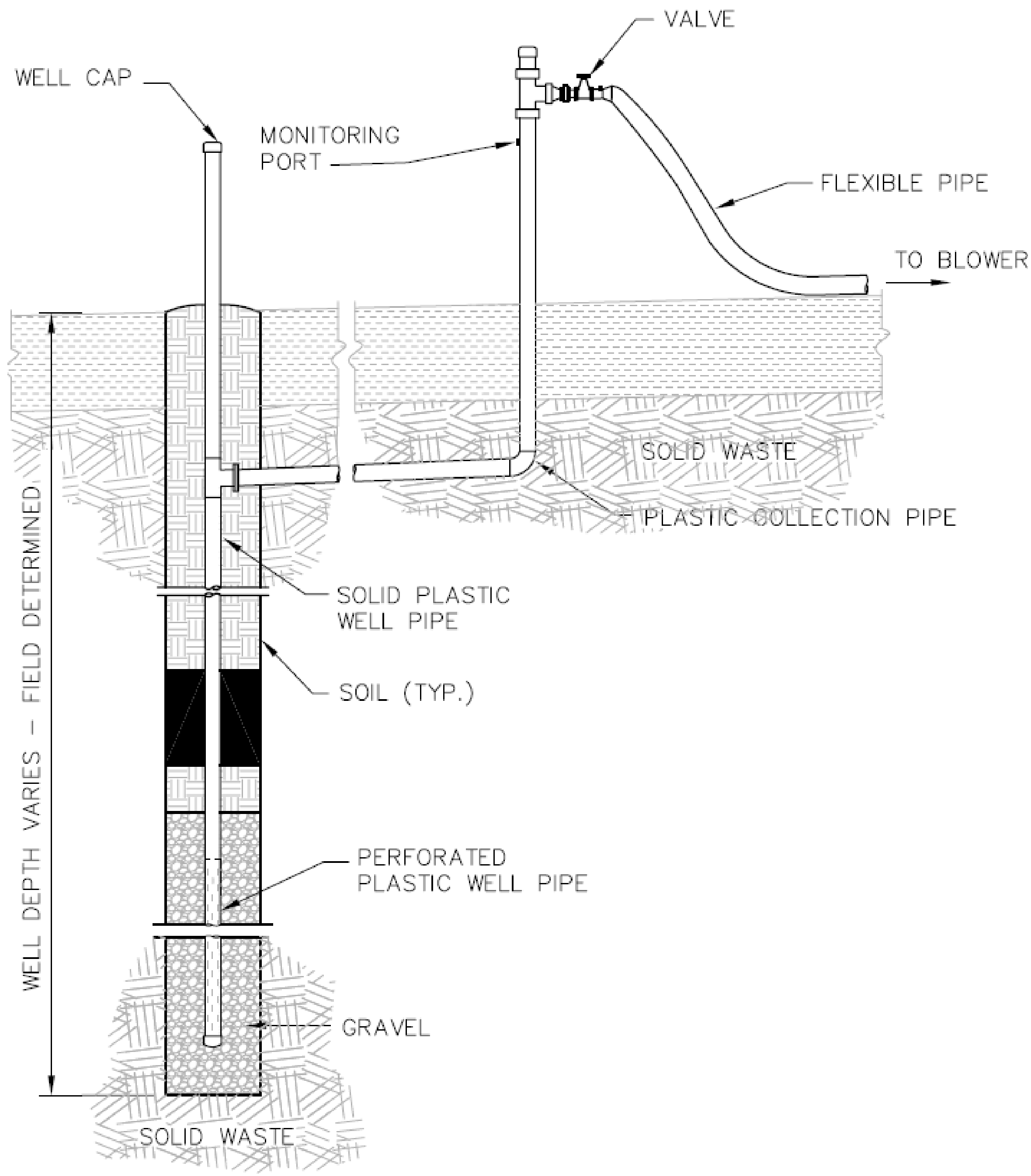

Figure 4: Typical cross section of the biogas extraction well

In general, gas quality under static conditions was observed to be generally very good methane levels, well 1 had 56% Methane and well 2 had 52% methane.

Evaluation of power potential

- Total volumetric flow rate of two wells: $\dot{V}_{tot} = 0.6 m^3 / \min$
- Average methane percentage: $m_f = 0.47$
- Methane volumetric flow rate

$$\dot{V}_{ch4} = 0.6 * 0.47 = 0.282 m^3 / \min$$

- Methane mass flow rate:

$$\dot{m}_{ch4} = \rho_{ch4} * \dot{V}_{ch4} = 0.51296 kg / \min$$

- Calorific value of organic methane: $NCV = 50.5 \text{MJ/kg}$
- Heat engine average efficiency: $\eta_{th} = 40\%$
- Total energy produced by the two wells:

$$\dot{E}_{2wells} = \dot{m}_{ch4} * NCV * \eta_{th}$$
$$\dot{E}_{2wells} = 0.51296 * 50.5 * 0.4$$
$$\dot{E}_{2wells} = 10.3618 MJ / \min$$
$$\dot{E}_{2wells} = 0.1727 MJ / S = 0.1727 MW$$

- Total Energy per successful well:

$$\dot{E}_{well} = 0.1727 MW / 2 = 86.35 KW$$

- Landfill area: $A = 200{,}000 m^2$
- Estimated number of wells: $N_T = 60$
- Expected number of successful wells: $N_s = 60 * .80 = 48$
- Total energy for the landfill :

$$\dot{E}_{tot} = 86.35 KW * 48$$
$$\dot{E}_{tot} = 4.15 MW$$

Therefore, the estimated power potential of the landfill is about 4.15 MW.

REFERENCES

Abu Qdais H. A (1987) . Solid Waste Management of Irbid City.: Current Practices and Possible Improvements, MSc. Thesis in Environmental Engineering, Jordan University of Science and Technology.

USEPA (1996), Turning A Liability into An Asset: A Landfill Gas-to-Energy Project Development Handbook, Landfill Methane Outreach Program, Washington DC, USA.

Gas-Sim Software Manual, Version 1.52. (2001), United Kingdom Environmental Agency.

USAID Jordan Economic Development Program
Salem Center, Sequleyah Street
Al Rabieh, Amman
Phone: +962 6 550 3050
Fax: +962 6 550 3069
Web address: **http://www.sabeq-jordan.org**