PALOS VERDES LANDFILL GAS TO ENERGY FACILITY

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ABSTRACT

A landfill gas collection system has been operated at Palos Verdes Landfill to prevent subsurface gas migration and control odors since 1973. The Palos Verdes Landfill Gas to Energy Facility (Facility), which has been operating since mid-1988, utilizes the collected landfill gas as a fuel in two steam generators producing steam at 1350 psig and 960°F. The steam is used to drive the turbine generator and produce approximately 9 MW gross of electricity using a conventional Rankine cycle for the power production. Several technologies were investigated prior to selecting the Rankine cycle.

During the first 2 years of firm operation, the availability of the Facility was approximately 96% including the plant annual maintenance outages. This Facility has successfully demonstrated that landfill gas can be combusted in boilers, reduce air emissions, and provide economic advantages to offset landfill closure costs.

INTRODUCTION

The Los Angeles County Sanitation Districts (Districts) operate and maintain the closed Palos Verdes Landfill and the energy recovery Facility. The Districts are a special purpose organization created by the California State Legislature for the management of solid wastes and wastewater, and are governed by a Board of Directors consisting of elected representatives of the cities and unincorporated areas which the Districts serve. The Districts currently manage over 21,000 tons of solid waste per day at four major landfills and process a total of over 500 million gal/day of wastewater at 11 major wastewater treatment and water reclamation plants. The Districts also operate two recycle centers, one transfer station, one refuse to energy facility and three landfill gas to energy facilities.

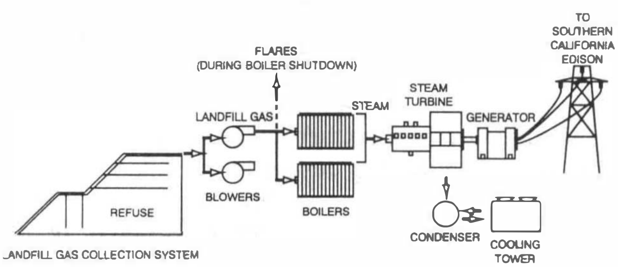

FIG. 1 SCHEMATIC OF THE PALOS VERDES LANDFILL GAS COLLECTION SYSTEM AND THE ENERGY RECOVERY FROM GAS FACILITY

The Palos Verdes Gas To Energy Facility, a 13 MW (rated gross) landfill gas to energy facility, commenced operation in mid-1988. The Facility is currently generating 9 MW gross (limited by the quantity of the landfill gas) and 8 MW net. During the first 2 years of commercial operation, the availability of the Facility approached 96%. This paper will present the operational information on this Facility including landfill gas production, collection, characteristics, emissions, availability, and economics. A schematic of the landfill gas collection system and the facility is shown in Fig. 1.

PALOS VERDES LANDFILL

The Palos Verdes Landfill is located in the foothills of the Palos Verdes Peninsula approximately 20 miles south of Los Angeles, California. It is owned by Los Angeles County (County) and the Los Angeles County Sanitation Districts (Districts), and operated by the Districts under a Joint Powers Agreement with the County. The landfill, which consists of three sections of land totaling 291 acres, was operated by the Districts from May 15, 1957 to December 31, 1980 when the site reached its ultimate capacity (23 million tons of solid waste). Virtually the entire 291 acre landfill site is surrounded by residential properties. The landfill is separated into three sections by Hawthorne and Crenshaw Boulevards. One section was developed by Los Angeles County as the South Coast Botanic Garden. The second section was developed by the City of Rolling Hills Estates as Ernie Howlett Park. The third section, the main site, consists of 173 acres with a maximum depth of waste of approximately 200 ft, and has an interim recreational use involving equestrian trails.

Prior to the construction of the gas to energy facility, the Districts collected landfill gas from the perimeter of the main landfill site and the South Coast Botanic Garden for the prevention of potential gas migration and odor control. A portion of the gas collected was utilized as fuel for a gas turbine-electrical generator set and the remainder was burned in three flare sections. The gas turbine facility operated from February 1983 to November 1987 and produced a net output of approximately 0.9 MW of electricity which was sold to Southern California Edison Company. A portion of the core gas at the main site was collected and sent to a gas recovery-purification facility, owned and operated by Getty Synthetic Fuels, Inc. (Getty), located at the Palos Verdes Landfill. The Getty facility began operation in 1975 and ceased operations on July 1, 1985.

LANDFILL GAS GENERATION

Landfill gas is produced by naturally occurring biological decomposition of the organic fraction of refuse. When refuse is landfilled, much of the organic fraction of the refuse will be converted to landfill gas over a period of 10–40 years. The rate of conversion depends on many factors including moisture content, refuse composition, nutrients, refuse compaction, and temperature.

Anaerobic production of landfill gas is approximately 60% methane and 40% carbon dioxide based on the District's experience. If oxygen is drawn into the landfill by the gas collection system, aerobic decomposition of the refuse, or composting, will occur. Composting produces carbon dioxide and water and raises the temperature of the landfill. It is necessary to draw limited quantities of air into the landfill for proper odor control. Accordingly, the landfill gas collection system is monitored to control odors and to minimize the amount of composting.

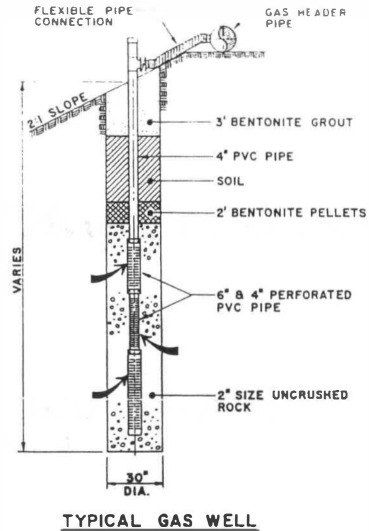

FIG. 2 LANDFILL GAS WELL DETAIL

LANDFILL GAS COLLECTION SYSTEM

An extensive landfill gas collection system has been operated at Palos Verdes Landfill since 1973. The gas collection system operation is optimized for gas migration prevention and odor control with power production as a secondary goal. The gas collection system consists of an extensive piping network of over 50,000 lineal feet of collection and header pipes, and 440 core and perimeter gas collection wells. The primary purpose of the gas collection system is to collect landfill gas and thus prevent odors and subsurface gas migration. Because of the landfill size and the extensive gas collection system in place, 6600 scfm of landfill gas is collected and utilized. The average heating value of the landfill gas is 200 Btu/scf measured on a dry basis.

The wells are monitored regularly for oxygen, temperature and methane content. A throttling valve on each well is used to control the tested parameters. A slight closure in the throttling valve results in decreasing the temperature and the oxygen, and increasing the methane content. A typical well detail is shown in Fig. 2.

Landfill gas delivered to the Facility is approximately 19% methane, 16% CO_2, 10% O_2, 50% N_2, and 5% H_2O (all by volume). Water and heat are byproducts of the refuse decomposition. Therefore, the landfill gas collected is normally warm and at 100% relative humidity or saturated when it comes out of the landfill. Accordingly, condensate traps are located at all low points on the gas collection system to collect condensates resulting from cooling of the landfill gas in the piping network. The collected condensate is treated by an air stripper to remove the volatile organics before discharge into the sewage system. The stripper off gas is recovered by the landfill gas collection system. Any volatile organic compounds are then combusted in the boilers.

The entire landfill gas collection system is under a vacuum to insure odorous gases do not escape in case a leak occurs in the piping. The landfill gas collection system at the Palos Verdes Landfill includes more than 50,000 ft of gas collection and header piping. The piping is subject to differential settlement and thermal expansion, which can cause expansion joints or other components of the landfill gas system to occasionally allow air intrusion into the system. Routine inspection and maintenance of the landfill piping has mitigated any problems associated with differential settlement. In addition, the overall gas collection system at the Palos Verdes Landfill is designed in a "loop" around the perimeter of the landfill. This allows the remainder of the collection system to be operational when part of the system is out of service for maintenance.

Normally there is a slight diurnal variation in the landfill gas quality with the Btu content lower at night. This may also be the result of thermal expansion of the PVC collection piping during the day, resulting in lower air infiltration into the above ground piping. The heating value of the landfill gas is monitored continuously by a calorimeter in the Facility. Sharp decreases in methane content of the landfill gas generally indicate breakages in the collection piping. The joint failure is immediately noted at the Facility as a change in gas Btu content. The repair of damaged joints is usually completed within a few hours.

TECHNOLOGY SELECTION

Several technologies to convert the landfill gas to electricity were investigated by the Districts. These technologies include reciprocating engines, gas turbines (simple and combined cycle), and the Rankine cycle. The study concluded that the most common technology used for electrical power generation in the United States, the Rankine cycle, was best suited for the Palos Verdes Landfill. The selection criteria included air emissions, energy conversion efficiency, ease of operation, landfill gas heating value suitability, construction cost and the partial load efficiency as shown in Table 1.

TABLE 1 SELECTION CRITERIA USED TO EVALUATE ALTERNATIVE LANDFILL GAS TO ENERGY TECHNOLOGIES FOR THE FACILITY

Criteria	Reciprocating Engine	Gas Turbine	Combined Cycle	Steam Turbine
Air Emissions	1	3	3	5
Net Power	4	3	5	4
Ease of Operation	2	3	2	3
BTU Content	2	4	4	5
Construction Cost	3	4	3	4
Partial Load Efficiency	4	3	3	5
Total Points	16	20	20	26

The Rankine Cycle's gas fired boiler with multiple control strategies, offered the ability to achieve very low air emissions, lower than any other of the technologies. Reciprocating engines had the highest emissions.

The combined cycle offered the highest net power, but at increased complexity and cost, which outweighed the value of the added power.

The "Btu Content" criteria included the ability to effectively operate on a low Btu content fuel, which is subject to sudden variations due to an increase in air infiltration as discussed earlier.

Two gas turbines have been operating at the Districts' Puente Hills Landfill since 1983: a Solar Centaur (2650 kW) and a NATCO KG-2 (1250 kW). Another NATCO KG-2 was operated at the Palos Verdes Landfill until November 1987, when the construction of the Facility was near completion. The gas turbines have operated successfully. The Districts consider gas turbines a viable technology for smaller landfills.

Since the Palos Verdes Landfill is a closed landfill site, the landfill gas generation rate gradually decreases with time as the waste degrades. The efficiency of the gas to energy facility at the partial load was an important factor in finalizing the selection of the technology. The steam turbine was determined to have the best energy conversion efficiency at partial loads.

PALOS VERDES GAS TO ENERGY FACILITY SPECIFICATIONS

In order to assure a competitive bid and quality construction, the Districts prepared detailed Performance

Specifications for bid to pre-qualified engineering and construction contractors. The Performance Specifications included detailed specifications on major equipment and general construction specifications. Also included in the Performance Specifications were the design, redundancy, and access requirements for all major equipment and systems. An equipment summary is provided in Appendix 1.

Bids were evaluated by calculating the net present worth of the 60 monthly payments and the residual value purchase payment to the bid opening using 1% per month discount rate. Net power from the Facility was included as an evaluated credit of $2500/kW to encourage energy efficient designs. However, the Performance Specifications included limitations on the cycle complexity for ease of operation and reliability, and several mandatory emission control methods to achieve the stringent air emission limitations.

The Performance Specifications included redundancy requirements on most rotating equipment for reliability. The only mechanical equipment without redundancy are the boilers (two, 50% each) and steam turbine. The successful bid by Mitsui & Co. (U.S.A.), Inc. included a steam turbine by Mitsui E&S. The steam turbine cycle heat rate is 9220 Btu/kWh at 100% design load. The boiler design efficiency is 84% of gross. The overall Facility's net heat rate based on the high heating value is approximately 12,200 Btu/kWh (net) with 9% parasitic load at the design conditions.

Performance requirements included ASME performance test codes for steam turbines, boilers, deaerator and CTI test for the cooling towers. The turnkey contractor was also required to demonstrate that the boiler could achieve the stringent limitations imposed on the project by the local air quality management district. Another requirement was to demonstrate the Facility could be operated reliably, which consisted of an 85% availability requirement for a 30-day period before the Districts accepted the Facility.

PROJECT SCHEDULE

A primary concern was to implement a project as quickly as possible to utilize the landfill gas. Project implementation, from conceptual design to full power operation, was accomplished in less than 3 years. Conceptual design was started in 1985. The contract was awarded to the turnkey contractor in July 1986. Full power operation was achieved in mid-1988 and the Districts accepted the plant from the turnkey contractor at the end of 1988.

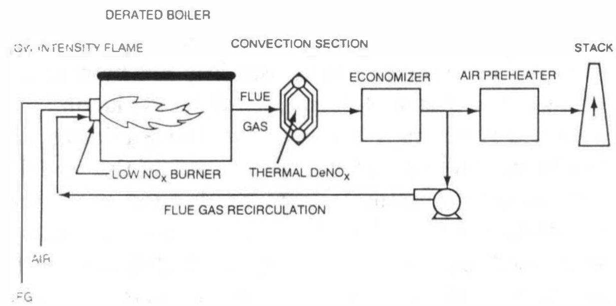

FIG. 3 SCHEMATIC OF THE PALOS VERDES GAS TO ENERGY FACILITY BOILER NO_x REDUCTION METHODS

The turnkey method of procurement was selected since it offered considerable time savings over other procurement methods. The turnkey contractor was required to design and construct the Facility in 16 months. The tight schedule mandated a substantial overlap of the design and construction phases of the work. A liquidated damage of $2000/day was imposed in the Specifications to encourage the contractor to meet the project schedule.

AIR EMISSIONS

Air emissions are a critical issue in Los Angeles County. From a regulatory standpoint the South Coast Air Quality Management District (SCAQMD) requires that all landfill gas be collected and controlled. When the permit was filed, the emissions from the flares, the gas turbine, and Getty Facility provided the baseline emission level.

The Performance Specifications included several requirements to assure the stringent emission levels could be achieved, including derating the boilers, flue gas recirculation, low NO_x burners, limiting the air preheat, and provisions for Thermal $DeNO_x$ (a proprietary Exxon process). Tests of Thermal $DeNO_x$ demonstrated that it did not effectively reduce NO_x at the low inlet NO_x levels. Subsequently, the ammonia injection piping was removed. The air pollution control and NO_x reduction methods are shown in Fig. 3.

The boiler burners are low NO_x burners supplied by John Zink. The burners are the dual air zone type (John Zink Model Number AVC-30D).

The NO_x control strategies including the low NO_x burners, oversized boilers, and flue gas recirculation have resulted in very low emissions of less that 24 ppmv NO_x (@3% O_2, dry) or approximately 0.03 lb/10^6 Btu. Flue gas recirculation has proven to be an effective method for reducing NO_x emissions by approximately 40%.

USING LANDFILL GAS AS A FUEL

The operations problems at Palos Verdes Gas to Energy Facility have for the most part been the result of failures with equipment common with a natural gas fired power plant. Any operational problems which could be attributed to landfill gas would be caused by the moisture, chlorine, or sulfur compounds and the variability in the Btu content of the landfill gas. The landfill gas is essentially saturated with water when it is collected from the landfill. Adequate drainage has to be provided for the condensate in the gas collection system to prevent boiler loss of flame due to introduction of slugs of condensate into boilers. Occasionally a condensate trap, which normally removes the condensate from low points in the landfill gas collection system, fails. This results in the partial or complete plugging of the associated piping until the condensate is removed. Partial plugging of the landfill gas pipe in the collection system is detected at the energy station by oscillating landfill gas pressures. When all the condensate traps are functioning properly, the landfill gas pressure is very stable.

Landfill gas is a relatively clean fuel. The landfill gas from Palos Verdes Landfill contains 20–30 ppmv each of chlorinated and sulfur compounds. The chlorine and sulfur in the landfill gas make the gas and its condensate corrosive. Since the landfill gas is saturated with water and the ambient temperature is below the dew point of the landfill gas, moisture condenses along the pipe walls. This condensation, or condensate has a pH between 2 and 3. Carbon steel corrodes quickly at this pH. Accordingly, the Districts use 304 stainless steel for both landfill gas and condensate piping at the Facility.

The Btu content of the landfill gas is important in the operation of the Facility. Normally the Palos Verdes Landfill gas varies from 190 to 210 Btu/scf on a dry basis. In the case of a piping expansion joint leakage, the Btu content may suddenly drop to below 150 Btu/scf. This may result in flame stability problems in the boiler and trip the boiler. As discussed previously, routine inspection and maintenance of the gas collection system has minimized these types of problems.

Flame stability in the boilers is a potential problem, especially using a high flue gas recirculation rate. Since the Palos Verdes landfill gas has very low heating value, approximately 20% of the Btu content of natural gas, the flame burns cooler. The pilot flame for startup is fueled by natural gas and the landfill gas is introduced after the boiler has reached a predetermined partial load. The Btu content of the landfill gas may decrease suddenly due to gas collection piping system leakages. This can cause an occasional burner safety management trip when the flame scanner (Fireye) fails to sense the flame. A supplemental firing of 260 SCFM (130 SCFM for each boiler) natural gas was determined by the boiler manufacturer to be a requirement to maintain the flame stability in the boilers and minimize burner caused trips.

Landfill gas is generally low in particulate matter. However, when new collection piping is placed in service or in upset conditions, an increase in particulate matter or moisture may be passed through the landfill gas piping. Stainless steel screens are located at the inlet of the landfill gas blowers to protect the blowers and remove particulate matter and slugs of condensate.

TABLE 2 FACILITY OUTAGE SUMMARY FOR JANUARY 1989–DECEMBER 1990

Item	Number of Outages	Total Downtime Hours
Steam Turbine	1	51
Boiler	9	87
Landfill Gas System	5	35
Electrical	2	6
Instrumentation	4	24
Utilities	10	100
Other Mechanical Equipment	13	136
Annual Maintenance Outage	2	268
Total	46	707

AVAILABILITY

The availability to date has been 96% for the first 2 years of operation after facility acceptance. For partial load operation either caused by equipment malfunction or during plant start-ups or shutdowns, the equivalent loss of power production hours is included in the calculation of availability. A summary of plant forced and planned outages affecting availability during the first 2 years of operation is given in Table 2.

The Mitsui steam turbine proved to be a reliable piece of equipment during the first 24 months of operation. The only outage directly related to the turbine was a planned outage to resolve an abnormal noise problem. The Facility is located very close to local residences, with the nearest residences located 300 ft to the northeast. In response to complaints from two local residents, the Facility was shutdown to investigate and mitigate the high sound level from the turbine. The turbine inspection showed the turbine was in good mechanical condition.

Out of the nine outages directly related to boilers, three partial outages took place to hydro-blast the air preheaters resulting in a loss of equivalent power production for 36 hr. A superheater tube rupture caused a loss of approximately 20 hr of equivalent production loss. Two outages occurred to repair a level gauge leak and a superheater header handhole leak. The other outages directly related to boilers were caused by operator errors.

The landfill gas collection system caused five outages in the first 2 years of operation. They were either caused by sharp drops in the landfill gas methane content or introduction of slugs of liquid from the landfill gas collection system to the Facility.

Five out of the ten outages related to utility power resulted from interruptions in service (3) or disturbances (2) resulting in the opening of the main breaker by protective relays. The remaining five outages were related to utility power system fluctuations resulting in generator trips (2) and boiler feedwater pump and landfill gas blower trips (3). Motors for boiler feedwater pumps and landfill gas blowers are controlled by the variable frequency drives (VFDs). The VFDs are very sensitive to voltage surges resulting in higher than normal rate of equipment failure due to utility system surges.

Thirteen outages were caused by other mechanical equipment: four outages by condenser vacuum problems; two outages by condenser tube leaks; three outages by boiler feedwater pump facilities; and four outages by high temperature and pressure pipe system leaks.

Annual maintenances have been typically scheduled in April or May, 1 or 2 months before the four summer months when power is sold at a higher rate.

Whenever the forced outages occur in the late evenings or early mornings, the plant restart efforts are delayed to mornings due to noise level restrictions. This restriction has caused an average of 25 hr of equivalent power production loss each year.

ECONOMICS

The project capital cost for the facility, including development cost spent by the Districts and the turnkey capital costs such as design, construction, and interest during construction was approximately $19,000,000. On a unit cost basis, this is equivalent to $1450/kW of installed capacity. The project financing was a cooperative effort between the County and the Districts under the Joint Powers Agreement. Economic benefits from the project will be shared by the County and Districts, and utilized to offset the maintenance costs of the closed landfill. The project financing was structured to allow the electrical revenues from the project to pay for the turnkey project capital costs with 60 equal monthly payments of $341,000 each. The average operating costs for the first 2 years of operation was approximately $300,000 per month.

CONCLUSION

The Palos Verdes Facility demonstrates that a small scale landfill gas to energy facility can combust landfill gas (a waste product), reduce air emissions, and provide economic benefits.

REFERENCES

Cosulich, J. and Eppich, J. "Puente Hills Energy Recovery from Gas (PERG) Facility," In *ASME Industrial Power Conference Proceedings*, 1988, pp. 55–60.

APPENDIX 1 PALOS VERDES GAS TO ENERGY FACILITY FACT SHEET

Owner and Operator	Los Angeles County Sanitation Districts/ Los Angeles County
Turnkey Contractor	Mitsui
Engineer (Detailed Design)	TMSI
Boilers	
Number	2
Manufacturer	Zurn
Steam Capacity (each), lbs/hr (kg/hr)	65,000(29,500)
Steam Pressure, PSIG (MPa)	1340(9.4)
Steam Temperature, °F (°C)	960(516)
Configuration	"O"Type
Erection	Shop
Burners	John Zink
Air Preheater (Plate Type)	North Atlantic
Stack Gas Temperature, °F (°C)	280(138)
Efficiency (as bid)	83%
Steam Turbine/Generator	
Manufacturer	Mitsui
Capacity	13,000 kw
Blading	Reaction
Number of Stages	37
Extractions	4
Condensing Pressure, "Hg (kPa)	2(6.8)
Heat Rate (as bid) @100% load	9220 BTU/kwhr (9.72 MJ/kwhr)
Condenser	
Manufacturer	Krueger
Surface Area, ft^2(m^2)	9,000(837)
Feedwater Heaters	
Manufacturer	Old Dominion Fabricators
Stages	3
Cooling Tower	
Manufacturer	Ceramic Cooling Tower
Heat Rejection, 10^6BTU/hr (MJ/hr)	77.6(81.6)
Superstructure	Concrete
Fill Material	PVC
Fans	50 hp, 2 speed
Control System	
Supplier	Bailey Control
Type	Distributed
Model	Network 90