CHAPTER 4
Design of Landfill Off-Gas Treatment Systems

4.1. **Introduction.** A blower/flare station is typically composed of the following components:

- Structure.
- Blower.
- Flare.
- Flame Arrestor.
- Flow Metering.
- Piping and Valves.
- Electrical controls.

4.2. **Structure.** The blower/flare station should be located on native soil and should be accessible by vehicles to allow for flare and blower maintenance. In inclement climates, all the basic equipment except the flare should be located within an enclosed structure. It should be noted that an enclosed blower/flare structure is classified as a Class I, Division I, and Group D Hazardous Location as defined by the National Electric Code. Therefore, all equipment housed in the building must be rated for this classification. In mild climates, the equipment does not have to be located within an enclosed structure. For most sites, a security fence should surround the flare station. Within the station, there should be ample access to units for maintenance activities and replacement.

4.3. **Blower**. The blower must be able to function under a range of conditions that may result due to changes in LFG composition and flow rate. The blower applies the required vacuum on the LFG collection system and supplies the required discharge pressure for the flare. The amount of vacuum required depends on the size of the LFG collection system and typically varies from 40 to 60 inches (1.02 and 1.52 meters) of water column. The amount of pressure required is governed by the flare burner configuration and typically varies from 10 to 20 inches (0.25 to 0.51 meters) of water column. LFG collection systems generally use centrifugal or positive displacement type blowers:

4.3.1. *Centrifugal Blowers.* These blowers are typically employed for applications requiring less than 203.2 cm (80 inches) of water vacuum. Centrifugal blowers are compact and produce an oil-free airflow. The principle of operation is as follows: A multistage impeller creates pressure through the use of centrifugal force. A unit of air enters the impeller and fills the space between two of the rotating vanes. The air is thrust outward toward the casing but then is turned back to another area of the rotating impeller. This process continues regenerating the pressure many times until the air reaches the outlet.

4.3.2. *Rotary Lobe Blowers.* These positive displacement blowers are typically used for a medium range of vacuum levels (roughly 50 to 460 cm (20 to 180 inches) of water vacuum). During operation of these blowers, a pair of matched impellers rotates in opposite directions, trap a volume of gas at the inlet, and move it around the perimeter to the outlet. Timing gears that are keyed into the shaft synchronize rotation of the impellers. Oil seals are required to avoid contaminating the air stream with lubricating oil. These seals must be chemically compatible with the site contaminants. When a belt drive is employed, blower speed may be regulated by changing the diameter of one or both sheaves or by using a variable speed motor.

4.3.3. *Blower Summary.* Centrifugal blowers are more commonly used due to their greater flexibility in adjusting to variable flow rates and lower long-term maintenance costs. Centrifugal blowers also result in power consumption savings when the flow rate is reduced due to the proportional decrease in horsepower. A comparison of centrifugal and positive displacement blowers is shown in the Table 4.1.

Table 4.1.
Blower Type Comparison.

Centrifugal	Positive Displacement
Lower long-term maintenance	Higher long-term maintenance
Direct driven (Generally)	Belt driven
Ample tolerances, little wear and tear of internal parts	Close tolerance of internal parts, more wear and tear. SAFETY NOTE: As parts wear, there is a possibility of metal to metal contact which could produce a spark with enough energy to ignite a flammable atmosphere.
Bearings mounted outboard of blower housing, no chance that discharged gas will be contaminated	Internally lubricated, more chance that discharged gas will be contaminated
Can deliver variable volume at constant speed	Delivers constant volume at constant speed
Less power used for lower flows	No power savings for lower flows, vent excess flows unless you change the speed at which the blower rotates through change in sheave size or use a VFD motor
Deliver relatively constant pressure at constant speed	Deliver variable pressure at constant speed
Less noise, easier to muffle	More noise, difficult to silence
Since horsepower is in direct proportion to flow, ammeter with volumetric scale can be used to approximate flow	Measurement of flow with an ammeter is not reliable, more expensive meter may be required
Produces a smooth, non-pulsating flow when operating at any point beyond the surge range	Produces a pulsating flow beyond the surge range

4.3.3.1. Since LFG may contain particulates and aqueous vapor that may be corrosive, a protective coating should be applied to all blower parts in contact with the gas. Flexible connections are recommended on both inlet and outlet sides of a blower to adsorb vibrations during operation. In addition, the blower motor should be explosion-proof and suitable for Class I, Division I, Group D, and Hazardous Locations. Both a temperature and pressure gage should be included on each side of the blower. These instruments aid in operating the blowers within the manufacturer's recommendations as well as the system at the desired flow rate.

4.3.3.2. Depending on the potential health hazards due to mechanical failure, a back-up blower is sometimes provided in the event the primary unit fails or is out of service for maintenance. In addition, design redundancy provides greater operating flexibility. Stand-by units not in service should be isolated from the LFG flow stream by butterfly or gate valves. These valves, when closed, will prevent accumulation of condensate from the LFG in the piping and blower casing. The valves can also be used to adjust the flow rate and allow removal of the unit for maintenance.

4.4. **LFG Energy Recovery Systems**. In large municipal landfills, LFG is being developed as an energy resource. Generally, the collection of gas for energy recovery purposes has been limited to large landfills with over 1 million tons of solid waste in place. Military landfills are typically smaller in size and often do not contain waste types conducive to the production of large enough quantities of methane to be economically recovered for use as an energy source. Energy recovery options are briefly discussed for the reader's information. The following four approaches have been used for LFG energy recovery:

- Fuel a gas turbine engine
- Generate electricity by the operation of a gas turbine or an internal combustion engine
- Fuel a boiler. Steam generated could drive a turbine/generator set up to produce electricity
- Upgrade the gas to pipeline quality for delivery to a utility distribution system.

Typical LFG contains approximately 500 Btu per standard cubic foot (4,450 K cal/m^3) of energy whereas pipeline-quality gas contains 1,000 Btu/scf (8,900 K cal/m^3). The energy content of LFG varies widely depending upon the performance of the gas collection system and the stage of decomposition within the landfill. Active extraction systems that draw excessive amounts of atmospheric air into the subsurface can also result in dilute influent gas streams.

4.5. **Flares.** Two types of flare systems are generally used for LFG off-gas collection and treatment systems: open-flame flares and enclosed flares. Each flare type has advantages and disadvantages. Both types of flares have been used for LFG treatment.

4.5.1. *Open-Flame Flare.* An open-flame flare or candle-stick flare represents the first generation of flares. The open-flame flare was mainly used for safe disposal of combustible gas when air emission control was not a high priority. Open-flame flare design and the conditions

- Simple design since combustion control is not possible.
- Ease of construction.
- Most cost-effective way of safely disposing of landfill gases.
- Open-flame flares can be located at ground level or elevated.

The major disadvantages of open-flame flares are:

- They do not have the flexibility to allow temperature control, air control, or sampling of combustion products due to its basic design.
- Sampling off-gas from open-flame flares is difficult. Sample probes placed too close to the flame will measure high CO_2 and hydrocarbon levels. Samples taken further away from the flame are diluted unpredictably by air.

4.5.2. *Enclosed Flares.* Enclosed flares differ from open flares in that both LFG and airflows are controlled. While a blower pushes LFG through the flame arrestor and burner tips, the flare stack pulls or drafts air through dampers and around burner tips. The stack acts as a chimney, so its height and diameter are critical in developing sufficient draft and residence time for efficient operation. Enclosed flares are more commonly used than open flares in LFG applications for two reasons:

- They provide a simple means of hiding the flame (i.e., neighbor friendly).
- Periodic sampling of these flares can be conducted to ensure the required rate of emissions reduction is being achieved.

A typical schematic of an enclosed flare system is shown in Figure 4.1. An enclosed flare burns LFG in a controlled environment to destroy harmful constituents. The basic flare unit consists of a multi-orifice burner and burner chamber enclosed in a stack containing refractory insulation. Usually the stack height is greater than the flame height so the flame is not visible to the public. The typical stack height is 20 to 30 feet. Exit gas temperature is measured by thermocouple and is recorded at the flare control panel. An automatic combustion air control system (dampers) operates based on the temperature controller. The dampers provide ambient air to the flare interior for combustion oxygen and for controlling the exit gas temperature. Sampling ports are located in the walls near the top of the stack where emissions monitoring are performed. A built-in staircase and platform is usually provided for access to the sampling areas. A flare will include an electric pilot ignition system. The pilot ignition system requires auxiliary fuel; therefore, a small propane tank must be located near the flare to serve as pilot fuel.

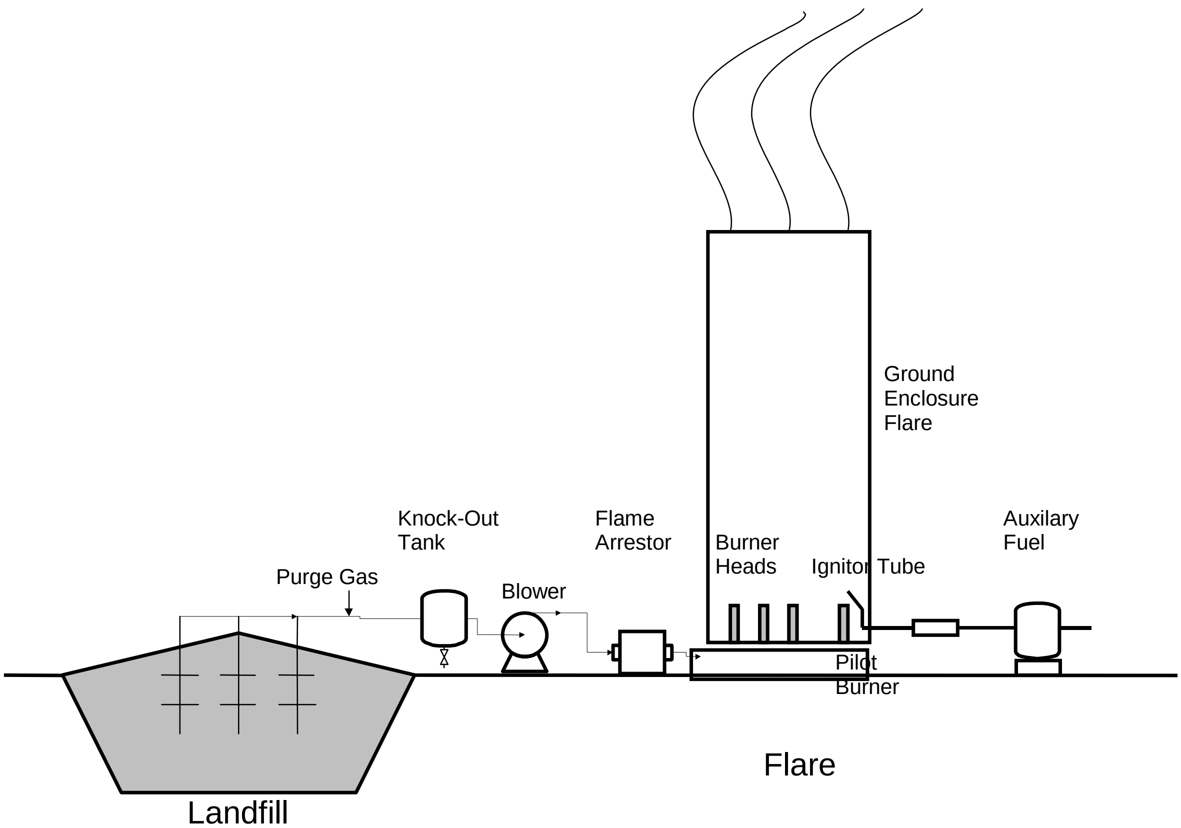

Figure 4.1. Enclosed Flare Schematic.

4.5.3. *Flare Design Criteria.* The basic flare unit consists of the following components:

- Multi-orifice burner
- Burner chamber.
- Automatic combustion air control system (dampers).
- Electric pilot ignition system.
- Sampling ports.
- Flare control panel.
- Temperature controller (flare stack high temperature interlock).
- Flame arrestor.
- Emission control.

4.5.3.1. The elements of combustion that must be addressed in the design of a LFG flare are:

- Residence time.
- Operating temperature.

- Turbulence.
- Oxygen concentration.

4.5.3.2. These elements are interrelated and, to some extent, dependent on each other. Adequate time must be available for complete combustion. The temperature must be high enough to ignite the gas and allow combustion of the mixture of fuel and O_2. The residence time in a combustor must be sufficient for hydrocarbons to react with the O_2. Residence times for VOCs can vary from 0.25 to 2.0 seconds. Solid particles, such as carbon, may require as long as 5 seconds for complete destruction.

4.5.3.3. The operating temperature of a combustion unit depends upon the material to be combusted. The temperature should be about 148 to 260^oC (300 to 500^oF) above the auto-ignition temperature of the LFG. CH_4 auto ignites at 540-760^oC (1000-1400^oF), thus a minimum operating temperature of 760^oC (1400^oF) is often specified. A temperature that is too high may cause refractory insulation damage as well as production of excess NO_x, while a temperature that is too low may result in the production of excess carbon monoxide and unburned hydrocarbons. Flare Stack high and low temperature alarms should be provided as well as a high-high interlock to shutdown the gas supply to the flare stack in the event of an excessively high temperature. Methane has a flame temperature of 1880^o C (3416^o F) when no excess air is present to cool the gas.

4.5.3.4. There must be enough turbulence to mix the fuel and O_2, and enough O_2 to support combustion. Mixing the LFG and air at the burner tip is critical to proper operation of the flare. Proper mixing and adequate turbulence will create a uniform mix of LFG and air in the combustion zone, whereas improper mixing will result in flue gas stratification, which contributes to high emissions and unstable operation.

4.5.3.5. Operating at high flow rates and tip velocities requires flame stabilizers to prevent the flame from extinguishing itself. Windshields allow the flame to establish itself and resist high wind conditions. Automatic pilots sense the LFG flame and automatically relight the flare when necessary.

4.5.3.6. A gas flow meter system is necessary to measure LFG flow to the flare. The gas flow should indicate both current flow and accumulated flow. For data storage, it is recommended that digital storage be used instead of paper recorder to avoid maintenance problems. The total volumetric flow rate to the flame must be carefully controlled to prevent flashback problems and to avoid flame instability. A gas barrier or a stack seal is sometimes used just below the flare head to impede the flow of air into the flare gas network.

4.5.3.7. Thermocouples are used to monitor the flame in open and elevated flares. For enclosed flares, ultraviolet (UV)-type flame detectors should be used. The UV flame detectors can detect instantaneous flame failure so the inlet valve can be shut before the vessel fills up with unburned gas.

4.5.4. *Flare Operating Criteria.* The design and selection of landfill flares depends upon the required design and operating objectives. In any case, flares should be designed and manufactured to provide the minimum operating temperature under a range of LFG compositions and flow rates. Other typical flare operating criteria include the following:

- Reactive Organic Gas (ROG).
- Exit Gas Temperature.
- Nitrogen Oxides (NO_x).
- Residence Time.
- Sulfur Oxides (SO_x).
- Carbon Monoxide (CO).
- PM10 (Particulate Matter of Aerodynamic diameter smaller than or equal to a nominal 10 microns).

4.6. **Condensate Collection Equipment.** Landfill gas is typically saturated with water vapor. As the gas cools in the extraction system piping, the vapor condenses into droplets that eventually combine into LFG condensate. Accumulations of condensate in LFG pipelines can obstruct the flow of gas. Therefore, LFG condensate must be removed in a controlled manner. Condensate control is required irrespective of how great a vacuum is imposed on the collection system. Knock-out tanks are normally used to remove condensate from gas entering the flare station. Low points in collector piping should have barometric drip legs installed and multiple arrays of piping should meet at common condensate knock-out tanks. Environmental regulations often require the treatment of collected condensate.

4.7. **Auxiliary Fuel.** Auxiliary fuel is required if the LFG methane content is too low to burn by itself. The operating temperature is a function of gas composition and flow rate. Unfortunately, LFG composition and flow rate are variable and somewhat unpredictable. LFG typically produces a maximum of 500 BTUs per cubic foot when it contains 50 percent methane. Natural gas produces approximately 1033 BTU per cubic foot. Fortunately, flares are manufactured which are able to provide the minimum operating temperature under a range of LFG compositions and flow rates. However, when the BTU loading derived from LFG is outside the flare design range, auxiliary fuel is required at the flare.

4.8. **Flame Arrestor.** Another important unit independent from the flare is the flame arrestor that is installed in the LFG inlet line. The function of the flame arrestor is to prevent the propagation of flame into the header pipes. The flame arrestor is packed with a flame quenching media that is durable, resistant to oxidation, and easy to clean. Pressure gauges and sampling ports must be installed on each side of the flame arrestor to indicate the degree of clogging and whether removal for cleaning is required. Proper sealing of the flame arrestor in the housing is essential. Since a flame arrestor requires periodic factory cleaning, a stand-by flame arrestor should be kept on-site for use during maintenance activities. Also, in selecting a flame arrestor, an easily removable design should be used to facilitate cleaning and inspection. The flame arrestor housing is generally carbon or stainless steel.

4.9. **Flow Metering.** An important additional piece of equipment at a blower/flare station is a gas flow metering system. LFG flow rate information is the basis for controlling operation of the extraction and treatment system. The gas flow meter should display current and total gas flow.

4.10. **Piping and Valves.** Cast iron or ductile iron materials are recommended. Flanged piping, valves, and fittings are also recommended. Hand-operated, wafer style butterfly valves are easiest to install and use for blower adjustments.

4.11. **Electrical Design Requirements**

4.11.1. *General.* The electrical system planning and design should consider materials, equipment, and installation of all electrical components. A detailed discussion electrical system planning is presented in EM 1110-1-4001. The following paragraphs outline some of the electrical control requirements unique to landfill gas flare systems.

4.11.2. *Electric Controls.* Necessary blower controls include:

- MANUAL/AUTO/OFF selector switch.
- Failure light.
- Time elapse meter.
- Motor ON/OFF light.

Normally, the blower is operated in AUTO mode that enables the blower to be automatically controlled from the control panel. The blower MANUAL operation is used only during testing. A time elapse meter is typically used to indicate blower operation duration and help establish the blower maintenance period. Electrical controls included on the flare control panel are:

- MANUAL/AUTO/OFF selector switch.
- Temperature controller.
- Pilot ON/OFF light.
- Temperature recorder.
- LFG ON/OFF light.
- Aux fuel ON/OFF light.
- Flame failure light.

Normally, the flare is operated in AUTO mode and requires an operator to push the start button to initiate flare ignition and blower operation.

4.12. **Automation of Controls.** A good instrumentation and control system design will assure that the individual components of the off-gas collection and control system are coordinated and operate effectively. This paragraph will present:

- Control elements
- Degree of automation
- Special instrumentation requirements.

4.12.1. *Control Elements.* At a minimum, the following process control components are required:

- Pressure and flow indicators for each well
- Blower motor thermal overload protection
- Vacuum relief valve or vacuum switch to effect blower shutdown
- Pressure indicators at blower inlet and outlet
- High-level switch/alarm for condensate collection system.

A typical piping and instrumentation diagram (P&ID) is shown in Figure 4.2.

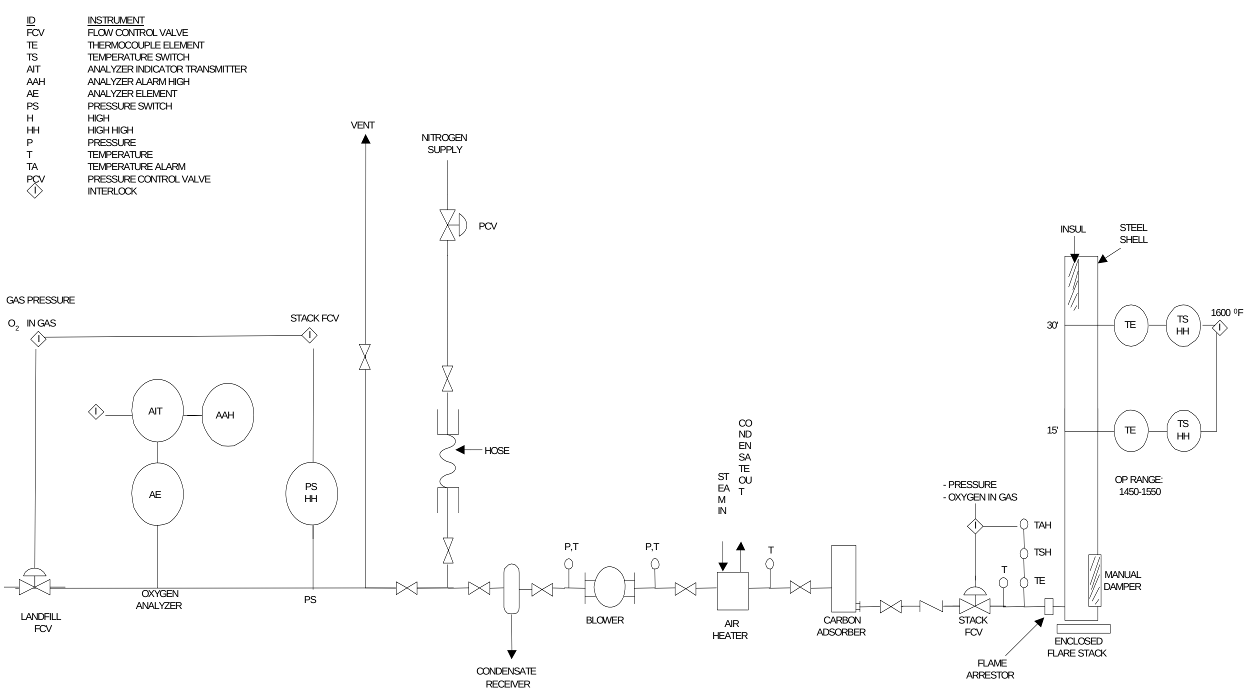

Figure 4.2. Typical Piping and Instrumentation Diagram (P&ID) for a Blower/Enclosed Flare Station.

4.12.1.1. *Gas Pressure Gauges.* Pressure gauges in the operating range of the gas management system are readily available commercially. Several types are available. The only design consideration beyond the pressure range is corrosion resistance to the compounds present in the landfill.

4.12.1.2. *Methane Gas Detectors.* Gas detectors may be placed in the feed manifold system of active collection systems to monitor the explosive range (or BTU content) of the recovered gas. Systems that burn the gas have different operating target values than systems that vent or otherwise dispose of the gas. Methane concentration data can be used to adjust landfill gas extraction and processing conditions. Infrared instruments that measure methane gas concentration in the manifold system may also be used.

4.12.1.3. *Alarms.* The gas control system will usually require several alarms to ensure safe and efficient operation. Alarms must be provided to ensure the condensate collection system does not overflow into the blower train. Alarms are required to alert for too rich or too lean a feed stream for combustion systems. Some blowers and vacuum pumps require alarms for overpressure or excessive vacuum in parts of the piping system. The system may also contain flow rate alarms to indicate too much or too little gas movement.

Some degree of alarm protection is provided in the electrical system that serves the blowers or pumps in the form of thermal overload systems, circuit breakers, or fuses.

4.12.1.4. *Control Panel Layout.* Scale drawings of the control panel should be prepared for all electrical components and associated wiring. Depending on the project, control drawings may be submitted as a shop drawing by the instrumentation and control contractor.

4.12.1.5. *Logic Diagram.* A logic diagram must be included if the process control logic is not apparent from the P&ID. This diagram shows the logical relationships between control components. For example, the diagram may show that if a particular switch is placed in the "on position" and there are no alarm conditions, then the blower will turn on and activate a green indicator light. Another example is when the alarm switch is placed in the on position, signaling that if the LFG is too rich, then the blower will be turned off to prevent explosive conditions in the flare.

4.12.2. *Degree of Automation.* The degree of automation is generally dependent on the complexity of the off-gas treatment system, the remoteness of the site, and monitoring and control requirements. Typically, there is a trade-off between the initial capital cost of instrumentation and control equipment, and the labor cost savings in system operation.

Systems designed for unattended operation would incorporate the greatest degree of automation of system controls. Control schemes may include the use of remotely located PLC, remote data acquisition, and modems and radio telemetry. System mechanical and electrical components would be selected on the basis of having optimum reliability while requiring minimum maintenance and adjustment.

There are three forms of process control: local, centralized, and remote. In a local control system, all control elements (i.e., indicators, switches, relays, motor starters, etc.) are located adjacent to the associated equipment. In a centralized control system, the control elements are mounted in a single location. These systems may include a hard-wired control panel, a programmable logic controller (PLC), or a computer. Remote control can be accomplished several ways including the use of modems or radio telemetry. To select the appropriate control scheme, the advantages and disadvantages of each control scheme must be considered. A localized control system is less complex, less expensive, and easier to construct. Centralized control systems are easier to operate. Automated process control is a complex topic that is beyond the scope of this document; however, several points are worth considering. Often plant operators will be more familiar with traditional hard-wired control logic than with control logic contained in software. However, process logic contained in software is easier to change (once the operator learns the software) than hard wiring.

4.12.3. *Special Instrumentation Requirements.* Additional information on instrumentation requirements can be found on the Technology Transfer Network. The Technology Transfer Network is a collection of technical Web sites containing information about many areas of air pollution science, technology, regulation, measurement, and prevention. The Emission Measurement Center (EMC) provides access to emission test methods and testing information for the development and enforcement of national, state, and local emission prevention and control programs. The EMC web site can be found at the following address: http://www.epa.gov/ttn/emc/.

4.13. **Other Design Considerations.**

4.13.1. *Site Working Areas.* Areas should be designated on the site plan for temporary storage. Access to the landfill should be provided to check pipe headers, wellheads, condensate traps, and sumps.

4.13.2. *Utilities.* Large landfills will need electricity, water, communication, and sanitary services. Remote sites may have to extend existing service or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines; potable water may be trucked in; and an electric generator may be used instead of having power lines run into the site.

4.13.3. *Emergency Power.* Many LFG extraction systems are equipped with emergency power sources such as generators to keep the blowers operating continuously. Generators should be designed to automatically turn on if the normal power supply fails.

4.13.4. *Water.* Water is sometimes required for cooling and sanitary use. A water supply may also be required for fire protection of buildings and or equipment.

4.13.5. *Fencing.* At some sites, it is desirable to construct perimeter fences to keep out trespassers and animals. If vandalism and trespassing are to be discouraged, a 1.8-m (6-foot) high chain link fence topped by 3 strands of barbed wire is desirable. A wood fence or a hedge may be used to screen site operations from public view.

4.13.6. *Lighting.* If the landfill has structures (employee facilities, administrative office, equipment repair, or storage sheds, etc.) interior lighting requirements need to be determined. Permanent security lighting may also be desirable in some situations. Refer to EM 385-1-1, Section 7 for lighting requirements.

4.13.7. *Labor Requirements.* LFG recovery systems typically do not require extensive labor commitments. A regular O&M schedule should be implemented to ensure the proper and uninterrupted operation of the system. Depending on the LFG control system installed and the size of the facility, one full-time operator may be needed to operate and maintain the gas collection system during the day. An automatic control system is designed to operate and control the system at night. Flare stations are often left unattended. In this case, a computer monitoring and control system will shut down the collection system and notify operators via an auto dialer in case of malfunction.

4.13.8. *System Safety*. Due to the explosive nature of landfill gas, flare station electrical equipment and fixtures should typically be classified accordance with 29 CFR 1910 Subpart S or NEC as Class 1, Division 2, Group D, or which ever is more stringent. Some local codes may be more restrictive than the aforementioned and should be examined before design.