Vacuum Sewer Systems and Their Use

A vacuum sewer system is used to collect wastewater from multiple sources and convey it to a central location where it can be treated. As the name suggest, a vacuum is drawn on the collection system. When a line is opened to atmospheric pressure, wastewater and air enter the system. The wastewater that enters with the air forms a “plug” in the line, and air velocity pushes the wastes toward the vacuum station. This differential pressure comes from a central vacuum station. In order to justify the cost of the vacuum station, at least 150 to 200 connections are needed. Vacuum sewers can take advantage of available slope in the terrain, but are most economical in flat terrain. Vacuum sewers have a limited capacity to pull water uphill. The maximum expected lift is between 30 and 40 feet. Vacuum sewers are designed to be watertight since any air leakage into the system reduces the available vacuum.

Vacuum sewers do not require a septic tank at each wastewater source. All of the domestic wastewater and waste constituents are collected and transported by this collection method. Sewage from one or more homes or businesses flows by gravity into a small valve pit. A service line connects the valve pit to the main vacuum line. Each valve pit is fitted with a pneumatic pressure-controlled vacuum valve. This valve automatically opens after a predetermined volume of sewage has entered the sump. The differential pressure between the valve pit (at atmospheric pressure) and the main vacuum line results in the wastewater being pulled through the service line. The amount of air that enters with the sewage is controlled by the time that the valve remains open. When the vacuum valves close, atmospheric pressure is restored inside the valve pit.

The sewage travels in the vacuum main as far as its initial energy allows, eventually coming to rest. As other valve pits in the network open, more sewage and air enter the system. Each input of energy moves
the sewage toward the central vacuum station. The violent action in the pipe tends to break up the larger suspended solids during transport.

Like gravity sewers, vacuum sewers are installed on a slope toward the vacuum station. Periodic upturns or ‘lifts’ are installed in the vacuum line to return it to a shallower elevation. Overall, the lines are installed in a saw-tooth or vertical zigzag configuration so that the vacuum created at the central station is maintained throughout the network.

Vacuum stations include two or more vacuum pumps and a large vacuum tank. The pumps run 3 to 5 minute cycles or long enough to create adequate vacuum in the system. The vacuum tank holds the vacuum on the collection network and prevents the vacuum pumps from having to operate continuously. As valve pits are activated, there is a loss in the vacuum (negative pressure) in the system. When the negative pressure reaches a threshold level, the vacuum pumps re-engage to pull more vacuum. When sewage reaches the vacuum station, it flows into a collection tank. Sewage pumps are then used to convey the collected sewage through a force main to the treatment component. As with vacuum pumps, multiple sewage pumps are used to provide a backup in case of pump failure.
VACUUM SEWER SYSTEMS

Because of the cost of a vacuum station, vacuum sewers are most appropriate for communities with 200 or more connections. However, in some circumstances, as few as 75 to 100 connections can be feasible. A typical vacuum station can pull from a 15,000-foot radius or serve about 1,200 connections. The general conditions conducive to the use of vacuum sewers include: unstable soil; flat terrain; rolling land with many small elevation changes; high water table; rocky conditions; new and denser urban development in rural areas; and sensitive ecosystems. Established communities that have historical neighborhoods with narrow streets and limited access can also effectively utilize vacuum sewers because the small diameter pipe and shallow excavation takes less area to install.

It is generally not advisable to use this technology in areas with low population and low population densities. Because the movement of wastewater depends upon the differential pressure created when valves open, long pipe runs with few connections can result in poor performance. The same problem is seen when connections are installed but are not yet in use. As a solution for this, temporary valve pits installed at strategic locations can be fitted with timer-controlled valves that allow air to enter even though wastewater is not being generated by the source.

Compatibility with Community Vision

Vacuum sewers are scalable. The system can be zoned (divided into sections) to accommodate the rate of build-out as well as to facilitate maintenance. Access locations to valve boxes and cleanouts (if required) will be evident at the soil surface but are not obtrusive. Higher population densities are well-accommodated with this option. If maintaining local charm while improving infrastructure is a priority, communities can preserve assets such as historical areas or heritage trees.

Vacuum stations are centrally located within their service area. Usually only a single vacuum pump station is required rather than multiple stations found in conventional gravity and low pressure networks. This frees up land, reduces energy costs and reduces some operational costs. No manholes are necessary and odors and risks associated with

Selecting any wastewater collection system option must be considered within the context of a community’s broad, long-range plans for land use. Changes in development patterns, population density, livability, and delivery of services will occur as a result of the choices made and these must all be taken into account.
hydrogen sulfide gas are significantly reduced because the system is sealed, air is introduced and detention times are short. Vacuum stations are quite large and expensive compared to effluent sewer or pressure sewer system components, but can be designed to blend into the landscape.

A particular problem with vacuum sewers is the noise and odor created by the central vacuum station. As air is drawn through the system, sewer gases are extracted. A good solution to this problem is to pass the exhaust air through a bio-filter, which can absorb much of the gas and reduce odors.

**Land Area Requirements for Vacuum Sewers**

The land area required for a vacuum sewer system is a function of the area required for installation of the valve pit, the vacuum network and the central vacuum station. Valve pits for single-family residences typically have a 10-gallon capacity and occupy a relatively small area. Tanks for multiple connections or commercial facilities may require larger capacity (depending upon daily wastewater volume) and thus occupy more space. The area disturbed during excavation of the valve pit will be larger than the dimensions of the valve pit and piping. Horizontal directional drilling (HDD) helps to eliminate the need for large, deep trenches that disrupt existing utilities, landscaping, roads and driveways with installation of conventional sewers. Vacuum system pipes are typically only four inches in diameter and thus a trencher or small excavator is often used for excavation.

Note that additional land area will be required for the treatment and dispersal components selected by the community.

**Construction and Installation**

A valve pit is located at each wastewater source or cluster of sources. Valve pits are typically prefabricated and ready to install. They must be properly oriented and set at the correct elevation to allow for gravity flow from the source. Anti-flotation measures are required in areas with high water tables. An air intake must be installed on the building sewer downstream of the plumbing house trap to ensure adequate venting for the valves. On lot excavation is typically accomplished using a backhoe. The service line from the valve pit to the vacuum main can also be installed with a backhoe, but this often results in over-excavation. Using a chain trencher instead will result in less property disruption and require less site restoration. Proper bedding and backfilling
techniques must be used to avoid settling over time. Service lines that connect valve pits to vacuum mains must be separated from potable water lines to avoid cross-contamination. Vacuum mains must also be separated from other utilities.

Piping for most vacuum sewer mains is O-ring gasketed PVC pipe, so solvent welding is not required. It is normally buried about 36 inches deep, but depths of 4 to 5 feet are not uncommon in colder climates. The small diameter piping used for vacuum sewers is flexible and can be routed horizontally around obstacles. Vacuum sewer mains can often be located outside of and adjacent to the edge of pavement. Division valves must be installed at branch/main intersections, both sides of a bridge and road crossings, both sides of areas of unstable soils, and at periodic intervals on long routs. Some local codes still require cleanouts at specified intervals.

Vacuum testing of both valve pits and mains is performed over the course of the installation and upon completion of the entire system. Overall, there is a significant amount of disturbance associated with the installation, but not nearly as much as with deeper conventional gravity sewers. Once installed, most components are either below ground or flush with finish grade. Licensing requirements for personnel who install vacuum sewer systems vary, but they must typically be licensed as a public utility contractor the state or region in which they work.

Regular service is important for all systems to ensure best long term performance to protect public health and the environment. This also protects the investment. Frequency of operation and maintenance is dependent upon wastewater volume, relative risk to public health and the environment as well as the complexity of any pretreatment components used prior to dispersal.

Maintenance Requirements

Effective operation of a vacuum sewer system begins with proper design and construction, but regular inspection of system components by staff or remote monitoring is critical. Vacuum stations can be remotely monitored via telemetry or visited daily to record pump running hours and lubricant levels. A variety of tasks must be performed on a regular weekly, monthly or semi-annual basis. These tasks include changing oil and oil filters on vacuum pumps; removing and cleaning inlet filters on vacuum pumps; testing all alarm systems; checking/adjusting motor couplings, and; checking operation of vacuum station shut-off and isolation valves. The operator must conduct external leak tests on all vacuum valves and check/adjust valve timing. Preventive maintenance includes annual visual inspections of valve pits and valves, as well as rebuilding controllers every 3 to 6 years and rebuilding valves every 10 years.

As with all mechanical devices, vacuum valves will fail with some frequency. When a valve sticks open the whole system has reduced vacuum. Locating the stuck valve may be time consuming and require
two persons. When a valve fails to open, wastewater will backup in the valve pit (and potentially into the source). These failures are easier to locate but can result in a backup or the discharge of sewage.

Good recordkeeping of system performance and costs is critical. The advent of web-based telemetry has greatly improved the operator’s ability to monitor system status. Vacuum sewer system operators must be capable, dependable and knowledgeable. About 2.5 to 3 hours per year per service connection is a good estimate for time commitment. Training and certification is advisable and will typically be required by the local jurisdiction.

Costs for Vacuum Sewers

Long term costs include vacuum station utilities, clerical costs, transportation, supplies/spare parts as well as miscellaneous expenses such as insurance and accounting. Additional costs will be incurred for equipment reconditioning and replacement by trained service providers. Vacuum station equipment has a life expectancy between 15 and 25 years, but there are annual costs associated with reconditioning that offset replacement. Vacuum valves must typically be rebuilt every 8 to 12 years and their controllers require rebuilding every 4 to 6 years.

The vacuum pumps and sewage pumps are the only elements of the vacuum sewer system that require electricity. It is reported that monthly power costs range from $1.66 to $3.34 per month per connection. Larger stations typically have lower power consumption per connection. Each vacuum station must have a standby electric generator to keep the system operating during electric power failures. Part of the energy cost must include the fuel needed to operate this backup power source.

Because 150 to 200 connections are needed before the cost of the vacuum station can be justified, this fact sheet will only investigate the cost of a 200-home community. The vacuum station given in this example is capable of handling more connections and so costs would come down if the full capacity of the station is used. Thus, at full capacity, the cost per connection would decrease. The costs given in this document are for comparison purposes only. The actual cost for a system will vary significantly depending on site conditions and local economics. The costs for the systems below include valve pits and controller valves at all connections, system piping, vacuum pumps and appurtenances, and sewage pumps and appurtenances. The extent of site disturbance and nature of the restoration required will
Vacuum Sewer Systems

also affect costs. The cost of treatment, disinfection and dispersal components that might follow this collection system is not included.

Table 1 provides cost estimation for the materials, installation, and maintenance of vacuum sewer system. These costs assume that the wastewater sources average about 200 feet apart, the topography is relatively flat, the contractor would charge 20% for overhead and profit, and there are no sales tax on materials. Engineering fees and other professional services are not included in the costs. With a vacuum sewer system, it is assumed that one vacuum pod will serve at least two sources. Thus, for a 200-connection community, there are only 100 vacuum pods. This example assumes that the utility will install and maintain the vacuum pods. Each lot owner will still need to install a building sewer to the nearest vacuum pod.

<table>
<thead>
<tr>
<th>Building Sewer to Vacuum Pod</th>
<th>Collection Network Cost including 100 Vacuum Pods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials and Installation</td>
<td>$1,800 - $2,700</td>
</tr>
<tr>
<td>Annual electricity</td>
<td>-0-</td>
</tr>
<tr>
<td>Annual O&amp;M</td>
<td>$16 - $24 per yr</td>
</tr>
<tr>
<td>60 year life cycle cost – present value (2009 dollars)</td>
<td></td>
</tr>
</tbody>
</table>

The costs provided in this document are for comparison purposes only. The actual cost for a collection system will vary significantly depending on site conditions and local economics. For localized cost investigations, consult the Cost Estimation Tool associated with these materials.

References
These materials were reviewed by the WERF Project Subcommittee including:

Tom Groves  
NE Interstate Water Pollution Control Commission

Mike Hines  
Southeast Environmental Engineering

Jim Kreissl  
Environmental Consultant

Jack Miniclier  
Charles City County  
Consultant

Eberhard Roeder  
Florida Department of Health

Larry Stephens  
Stephens Consulting Services

Jeff Moeller  
WERF Senior Program Director

This Fact Sheet was prepared by members of the Consortium of Institutes for Decentralized Wastewater Treatment (CIDWT), including:

John R. Buchanan, PhD, PE  
University of Tennessee

Nancy E. Deal, MS, REHS  
NC State University

David L. Lindbo, PhD, CPSS  
NC State University

Adrian T. Hanson, PhD, PE  
New Mexico State University

David Gustafson, PE  
University of Minnesota

Randall J. Miles, PhD  
University of Missouri
