Vacuum Sewers: Components, Operation, and Advantages

The use and acceptance of alternative collection systems like vacuum sewers have expanded greatly in the last 30 years.

Thirty years ago, vacuum sewers were regarded as "new" and only to be used as a system of last resort. Improvements in the technology later led to acceptance as "alternative" sewers, but still only to be used when significant savings would result. Now, vacuum sewers have become an acceptable alternative in the proper application and provide efficient and reliable sewer service to communities all around the world.

Vacuum sewerage is a mechanized system of wastewater transport. Unlike gravity flow, vacuum sewers use differential air pressure to move the sewage. A central source of power to operate vacuum pumps is required to maintain vacuum (negative pressure) on the collection system. The system requires a normally closed vacuum/gravity interface valve at each entry point to seal the lines so that vacuum can be maintained. These valves, located in valve pits, open when a predetermined amount of sewage accumulates in collecting sumps. The resulting differential pressure between atmosphere and vacuum becomes the driving force that propels the sewage towards the vacuum station.

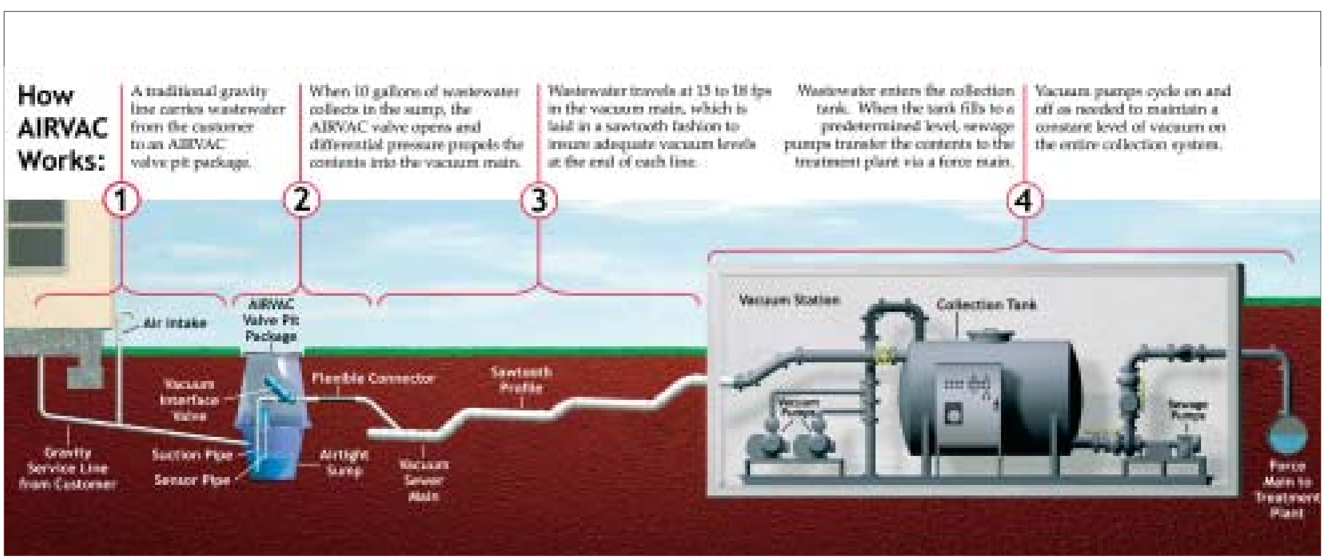
A vacuum sewer system consists of three major components: the vacuum station, the vacuum mains, and the valve pits.

Vacuum station. Vacuum stations function as transfer facilities between a central collection point for all vacuum sewer lines and a pressurized line leading directly or indirectly to a treatment facility.

Vacuum created by vacuum pumps located at the vacuum station is transferred through the vacuum mains and to the valve pit. The vacuum pumps do not run continually, but rather in cycles. They run for a short period, usually three to five minutes, to establish the high level of 20 in. of Hg vacuum. When this level is achieved, they turn off. As valves throughout the system open and admit atmospheric air, vacuum levels gradually drop. When the vacuum level reaches 16 in. of Hg vacuum, the vacuum pumps come on again and run to re-establish the 20 in. of Hg vacuum.

Sewage from the vacuum mains enters the collection tank and accumulates in the bottom part of the tank. When enough accumulates, the sewage pumps come on and pump the sewage out of the collection tank through a force main to the ultimate point of disposal.

Vacuum mains. The resulting pressure differential between the positive



pressure of atmosphere air and the negative pressure in the vacuum main becomes the driving force that propels the sewage towards the vacuum station. The pressure differential that exists at the normal operating vacuum levels provides the energy to propel the sewage at velocities of 15 to 18 fps.

When the sewage enters the vacuum main it travels as far as its initial energy allows, until frictional forces cause it to come to rest. As other valves in the piping network open, additional slugs of sewage and air enter the system. Each subsequent energy input continues to move the sewage toward the vacuum station.

Valve pit. The valve pit is where the interface between gravity and vacuum occurs. Valve pits and sumps are needed to accept the wastes from the house.

The vacuum valve provides the interface between the vacuum in the collection piping and the atmospheric air in the building sewer and sump. System vacuum in the collection piping is maintained when the valve is closed. With the valve opened, system vacuum evacuates the contents of the sump.

Technical Details

The entire process, from the house to the vacuum station, is described in more detail below.

House to valve pit. As far as the homeowner is concerned, connecting to a vacuum system is similar to connecting to any other sewer system. Sewage flows by gravity away from the house through a small diameter PVC pipe to the point of connection of the public sewer system. In this case, the point of connection is the valve pit.

A four-in. air-intake is installed on the homeowner's building sewer, downstream of all of the house traps. This air-intake is necessary to provide the volume of air that follows the sewage into the main resulting in the pressure differential that becomes the driving force. This also circumvents the problem of inadequate house venting, which can result in trap evacuation. Some operating entities require the air-intake to be located near a permanent structure for aesthetic and protection reasons. In some instances, local ordinances may stipulate a minimum setback distance from the building structure.

In the valve pit. The valve pit may consist of one unit with two separate chambers. The upper chamber houses the vacuum valve and the bottom chamber is the sump into which the building sewer is connected. These two chambers are sealed from each other. The combination valve pit/sump is usually made of fiberglass, and is able to withstand traffic loads.

Housed in the top chamber of the valve pit is an interface valve. This valve is normally closed to seal the vacuum mains. This ensures that vacuum is maintained on the piping network at all times. The valve is entirely pneumatic by design, and has a three-in. opening size. Some states have made this a minimum size requirement, as this matches the throat diameter of the standard toilet.

The lower chamber of the valve pit is a sump that receives the sewage from the house. When ten gal of sewage accumulates in the sump, the interface valve automatically opens. This is done without any electrical power being required. The valve opens and in three to four seconds, the contents of the sump are evacuated. The valve stays open for another two or three seconds to allow for atmospheric air to enter the system. This air comes from the air-intake located by the house.

Buffer tanks are used for large customers or when a pressure/vacuum or gravity/vacuum interface is desired, as would be the case with a hybrid system.

In the vacuum mains. Many view the vacuum pipeline as a "vacuum-assisted gravity sewer." Like gravity sewers, vacuum sewers are installed with a positive slope toward the vacuum station. When vacuum mains start to become deep, a "lift" is used to return the main to a more acceptable depth. It is at these lifts that vacuum "assists" the sewage on its travel toward the vacuum station. These lifts are made in a saw-tooth fashion. A single lift consists of two 45-degree fittings connected with a short length of pipe.

The saw-tooth configuration of the vacuum mains is a key feature of a vacuum system. The saw-tooth profile is used to keep an open passageway on the top of the piping network, thereby preventing the pipe from becoming sealed. By doing this, air flows above the liquid, and the vacuum that is created at the vacuum station can be transferred to every valve pit. This ensures that the maximum pressure differential, and hence, maximum energy, can be obtained at each valve pit.

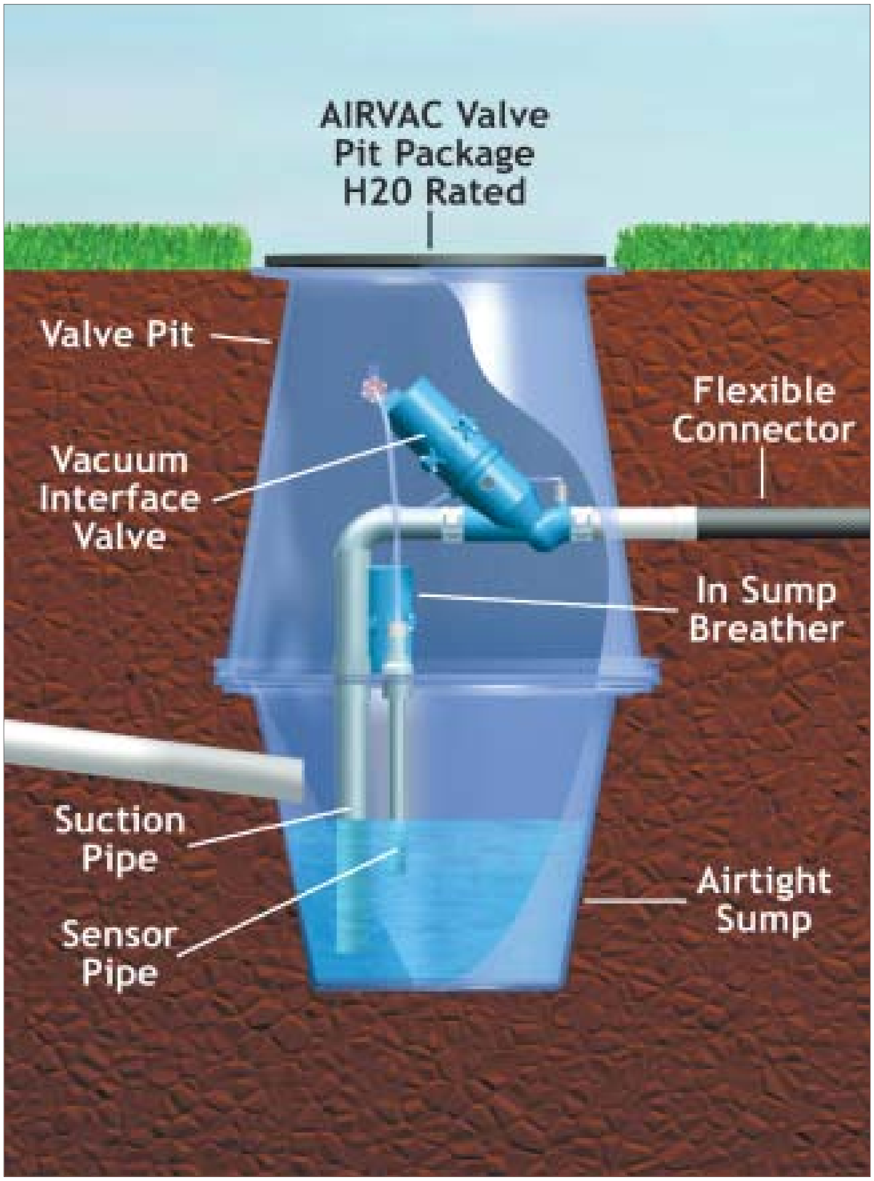
Schedule 40, SDR 21 or SDR 26 PVC pipe is used, with SDR 21 being the most common. Early systems used solvent-welded joints, but most recent systems use O-ring rubber gasketed pipe. Where gasketed pipe is used, the gaskets must be certified for use under vacuum conditions. Typical sizes include three-, four-, six-, eight-, and ten-in. pipe.

PVC pressure fittings are needed for directional change as well as for the crossover connections from the service line to the main line. These fittings may be solvent-welded or gasketed. The recent trend is to avoid solvent-welded fittings where possible, although there is a cost trade-off to consider, as the gasketed fittings typically are more expensive, but are less labor intensive than the solvent-welded fittings.

Division valves are used to isolate various sections of vacuum mains thereby allowing operations personnel to troubleshoot maintenance problems in a timely fashion. Both plug and resilient-wedge gate valves have been used, although most recent systems use gate valves. Some designs have included gauge taps installed just downstream of the division valve. This tap makes it possible for one person to troubleshoot without having to check vacuum at the station. This greatly reduces emergency maintenance expenses, both from a time and manpower standpoint.

Different pipe location identification methods have been used. These include magnetic trace tape in the top of the trench, metal-toning wires above the pipe during construction, utility frequency based electronic markers, and color-coding of the pipe itself.

At the vacuum station. Eventually the sewage reaches the vacuum station. The vacuum station has three major components: the collection tank, the



The valve pit is where the interface between gravity and vacuum occurs. Valve pits and sumps are needed to accept the wastes from the house.

vacuum pumps, and the sewage pumps. The vacuum pumps and the vacuum mains are connected to the top part of the collection tank. This part of the tank is kept open so that the 16 to 20 in. Hg vacuum that is created by the vacuum pumps can be transferred to the vacuum mains and ultimately to the valve pits.

Vacuum pumps may be either the liquid-ring or sliding-vane type, although most recent systems use the sliding vane type. Efficiency in the normal operating range is often cited as the reason for this. The optimum operating range is 16 to 20 in. Hg. The vacuum pumps, however, should have the capability of providing up to 25 in. of Hg as this level is sometimes needed during emergency conditions and in the troubleshooting process. Redundancy is required, as design capacity must be met with one pump out of service.

Discharge pumps are required to transfer the liquid that is pulled into the collection tank by the vacuum pumps to its ultimate point of disposal. Dry pit pumps have been used extensively, although submersible sewage pumps located on guide rails within the collection tank may be used as an alternative. The most frequently used pump has been the non-clog type. Redundancy is required, with each pump capable of providing 100 percent of the design capacity. The level controls are set for a minimum of two minutes pump running time to prevent excessive pump starting and related increased wear. The pumps should have shutoff valves on both the suction and discharge piping to allow for removal during maintenance without affecting the vacuum level.

Check valves are used on each pump discharge line or on a common manifold after the discharge lines are joined to it. Equalizing lines are to be installed on each pump. Their purpose is to equalize the liquid level on both sides of the impeller so that air is removed. This ensures that the impeller is filled with liquid, which allows the discharge pump to start without having to pump against the vacuum in the collection tank. Since this setup will result in a small part of the discharge flow being re-circulated to the collection tank, a decreased net pump capacity results.

Discharge pumps are typically located at an elevation below the collection tank to minimize the net positive suction head (NPSH) requirement. In conjunction with NPSH requirements, pump heads (TDH) must be increased by 23 ft to account for collection tank vacuum. Both vertical and horizontal pumps can be used.

Materials of construction for discharge pumps are commonly cast iron with stainless steel shafts. Cast aluminum, bronze, and brass should be avoided. Double mechanical seals, which are adaptable to vacuum service, should be used.

An emergency (or standby) generator is a must. It ensures that on-lot flooding or backup will be prevented through the continuing operation of the system in the event of a power outage.

The wastewater is stored in the collection tank until a sufficient volume accumulates, at which point the tank is evacuated. It is a sealed, vacuum-tight vessel made of carbon steel, fiberglass, or stainless steel. Fiberglass or stainless steel tanks are generally more expensive, but do not require the periodic maintenance of a carbon steel tank, which may require painting every five to six years. Vacuum, produced by the vacuum pumps, is transferred to the collection system through the top part of this tank.

The part of the tank below the invert of the incoming vacuum collection lines acts as the wet well. A bolted hatch provides access to the tank should it be necessary.

Most collection tanks are located at a low elevation relative to most of the components of the vacuum station. This minimizes the lift required for the sewage to enter the collection tank, since sewage must enter at or near the top of the tank to ensure that vacuum can be restored upstream. This may result in a deep basement required in the vacuum station.

Vacuum switches located on the collection tank control the vacuum pumps. The usual operating level is 16 to 20 in. of Hg with a low level alarm of 14-in. of Hg. Seven probes, one for each of the six set points of the pumping cycle and one as a ground, are located inside of the collection tank and control the discharge pumps.

The vacuum system control panel houses all of the motor starters, overloads, control circuitry, and the hours run meter for each vacuum and sewage pump. The vacuum chart recorder, collection tank level control relays, and fault monitoring equipment are also normally located within the vacuum system control panel. Fault monitoring systems include telephone dialers or other telemetry equipment including radio based SCADA systems, digital or fiber optic based SCADA systems, and telephone based SCADA communications systems.

Vacuum gauges, required to allow the operator to monitor the system, are used on all incoming lines as well as on the collection tank. These gauges are important in the troubleshooting procedures. Chart recorders for both the vacuum and sewer pumps are needed so that system characteristics can be established and monitored.

It is standard practice in the United States for the vacuum station equipment to be supplied by the vacuum manufacturer who pre-assembles and tests the equipment and then ships it to the jobsite on skids. These skids can then be lifted into the building and connected to the incoming vacuum mains and the outgoing force main.

The vacuum station equipment must be installed in a protective structure. Materials of construction are the choice of the consulting engineer and typically are selected to match the architecture of the surrounding community.

Applicability

Experience has shown that for vacuum systems to be cost effective, a minimum of 75 to 100 customers (houses or equivalents) per vacuum station is generally required. The average number of customers per station in systems presently in operation is about 200 to 500, but that average is increasing every year.

Vacuum systems are to a degree limited by topography. The most successful applications have been in relatively dense developments with moderate terrain changes. The vacuum produced by a vacuum station is generally capable of lifting sewage 15 to 20 ft, depending on the operating vacuum level of the system. This amount of lift is often sufficient to allow the designer to avoid all or many of the lift stations that would be required in a conventional gravity system.

The consulting engineer usually drives the community's choice of collection system type during the planning stages of a wastewater facilities project. This choice is normally based on the result of a cost-effectiveness analysis. While gravity may appear to be less costly in situations where the terrain is favorable for gravity flow, many small factors considered collectively may result in a vacuum system being the proper choice. Below are the general conditions that are conducive to the selection of vacuum sewers.

- Unstable soil
- Flat terrain
- Rolling land with many small elevation changes
- High water table
- Restricted construction condition
- Rock
- New urban development in rural areas
- Existing urban development where built-out conditions exist
- Sensitive eco-system

Advantages

The advantage of vacuum collection systems may include substantial reductions in water use, material costs, excavation costs, and treatment expenses. In short, there is a potential for overall cost effectiveness. Specifically, the following advantages are evident:

- Small pipe sizes, usually 4-, 6-, 8- and 10-in. are used.
- No manholes are necessary.
- Field changes can easily be made as unforeseen underground obstacles can be avoided by going over, under, or around them.
- Installation of smaller diameter pipes at shallow depths eliminates the need for wide, deep trenches reducing excavation costs and potential dewatering costs.
- High scouring velocities are attained, reducing the risk of blockages and keeping wastewater aerated and mixed.
- Elimination of the exposure of maintenance personnel to the risk of H_2S gas hazards.
- The system will not allow major leaks to go unnoticed, resulting in a reduced environmental damage from exfiltration of wastewater.
- Only one source of power, at the vacuum station, is required. No on-lot power demand exists at valve pits.
- The elimination of infiltration permits a reduction of size and cost of the treatment plant.
- Vacuum stations can be designed to blend with the surroundings more so than traditional lift stations.
- Valve pits are more concealable at the customer's property than are grinder pump stations.
- A single source responsibility exists as one operating entity operates and maintains the entire system, including the on-lot valve pit and valve. GE

Courtesy of AIRVAC (www.airvac.com).