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## Vacuum Sewers - Design and Installation Guidelines

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# Vacuum Sewers

# Design and Installation Guidelines

## PDHengineer Course No. C-8015

Portions of this course use material excerpted from *Alternative Sewer Systems,* 2nd ed.; Manual of Practice No- FD-12.

# I. INTRODUCTION

From the time the very first public sewer system was constructed until the 1960's, a conventional gravity system was the only choice US engineers had when considering a public sewer collection system. This changed about 40 years ago when the USEPA challenged the industry to developed alternative collection by providing special funding for such endeavors. One of the alternative collection systems is vacuum sewers.

At one time, 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 are providing efficient and reliable sewer service to communities all around the world. However, proper design is of utmost importance for these systems to perform efficiently.

This course is Part II of a three part series on vacuum sewers and will focus on detailed design and installation guidelines for vacuum sewer systems. Part I discusses the basics of vacuum sewer technology by providing a broad overview of the technology while Part III focuses on the Operation & Maintenance and System Management aspects related to vacuum sewers.

# II. HOW IT WORKS

## *A. Theory of Operation*

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.

## *B. The process – from the house to the vacuum station*

Figure 1 and the following discussion describe the vacuum sewer process of the wastewater's travel from the house to the vacuum station. A more detailed description of the major system components is found later in this course.

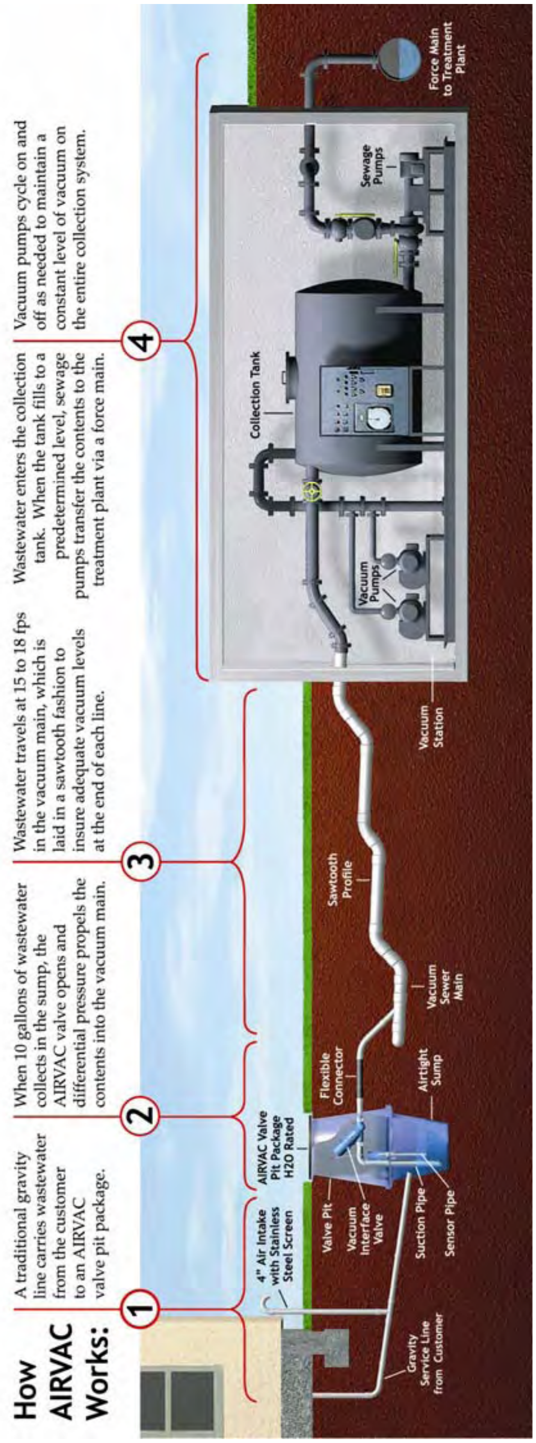


Figure 1
How it Works
(Courtesy AIRVAC)

**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 (Figure 2). In this case, the point of connection is the valve pit.

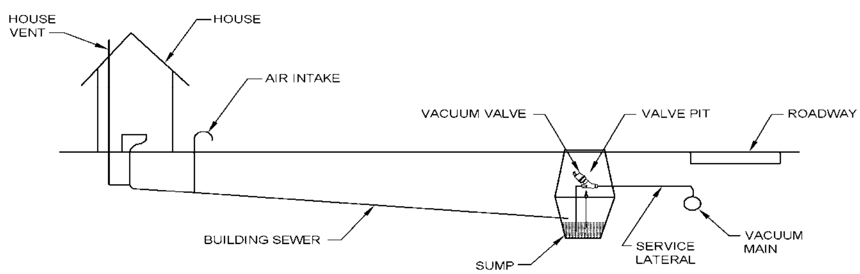


Figure 2
House / Pit / Main Relationship
(Courtesy AIRVAC)

**In the valve pit**

Vacuum created by vacuum pumps located at the vacuum station is transferred through the vacuum mains and to the valve pit. The valve pit is where the interface between gravity and vacuum occurs.

Housed in the top chamber of the valve pit is an interface valve. This valve is normally closed in order to seal the vacuum mains. This ensures that vacuum is maintained on the piping network at all times.

The lower chamber of the valve pit is a sump that receives the sewage from the house. When 10 gallons 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 3-4 seconds, the contents of the sump are evacuated. The valve stays open for another 2 or 3 seconds to allow for atmospheric air to enter the system. This air comes from the air-intake located by the house.

**In the 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 15-18 fps.

When the sewage enter 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.

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.

The lifts are part of the saw-tooth configuration of the vacuum mains, which 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.

**At the vacuum station**

Eventually the sewage reaches the vacuum station. The vacuum station has 3 major components: the collection tank, the vacuum pumps and the sewage pumps (Figure 3).

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 - 20 in. mercury vacuum that is created by the vacuum pumps can be transferred to the vacuum mains and ultimately to the valve pits.

The vacuum pumps do not run continually, but rather in cycles. They run for a short period, usually 3 to 5 minutes, in order to establish the high level of 20-in. of mercury 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 mercury vacuum, the vacuum pumps come on again and run to re-establish the 20- in. of mercury 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.

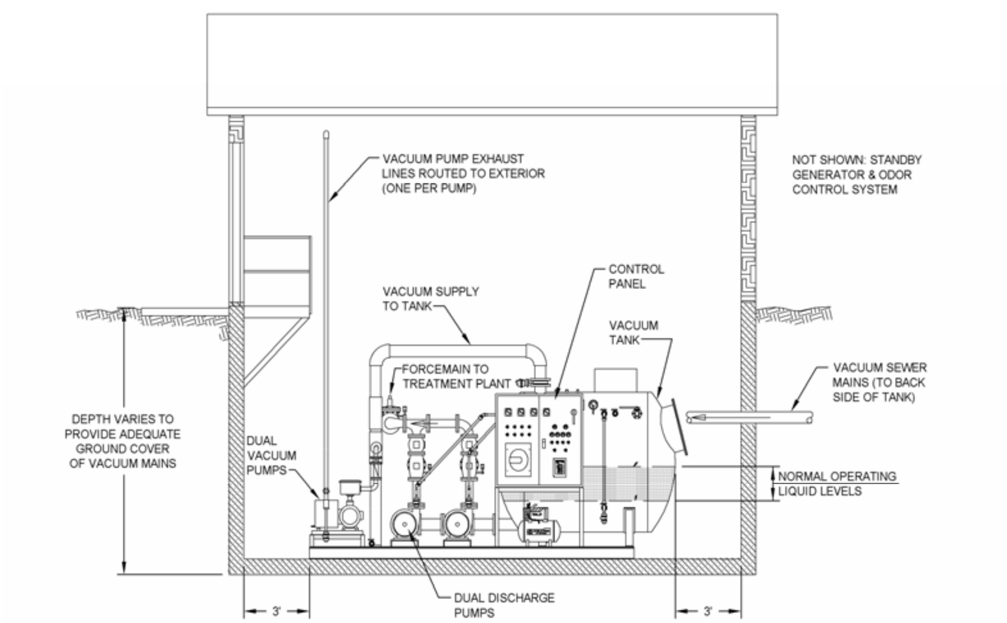


Figure 3
Components of a Typical Vacuum Station
(Courtesy AIRVAC)

# III. SYSTEM DESIGN CONSIDERATIONS

This section provides a general overview pertaining to the design of the various components of a vacuum system. The reader is referred to the 2005 version of AIRVAC's Design Manual[1] for additional and more detailed design information.

## *A. Hydraulics*

All of the major vacuum system components are sized according to peak flow, expressed in gallons per minute (gpm). Peak flow rates are calculated by applying a peaking factor to an average daily flow rate.

Design flows are maximum flow rates expected to occur once or twice per day, and are used to size the vacuum sewer mains and the various vacuum station components. Instantaneous flow rates in excess of design flows can occur under certain situations.

**Average Daily Flow (Qave)**

Based on the current Ten State Standards, sewage flow rates shall be based on one of the following:

1. Documented wastewater flow for the area being served. Water use records are typically used for this purpose.

2. 100 gallons per person per day combined with home population densities specific to the service area. Most approval agencies will accept published U.S. Census Bureau home density for this criterion.

**Peaking Factor (PF)**

The peaking factor suggested by the design firm should be used, with one exception: the minimum peaking factor should never be less than 2.5.

If not established by the consulting firm, regulatory agency or other applicable regulations, the peaking factor should be based on the following formula:

$$\frac{18 + \sqrt{POPULATION/1000}}{4 + \sqrt{POPULATION/1000}}$$

For example, if the service area has a population density of 1200, the peaking factor would be:

$$\frac{18+\sqrt{1.2}}{4+\sqrt{1.2}} = 3.75$$

Table 1 shows peak factors for various populations. Please note that these are not the exact figures that would be returned by the formula but rather are rounded figures for presentation purposes only.

**Table 1**

Peak Factors
Based on Ten State Standards formula

| Population | Peak factor |
|---|---|
| 100 | 4.25 |
| 500 | 4.00 |
| 1200 | 3.75 |
| 2500 | 3.50 |
| 5000 | 3.25 |
| 9000 | 3.00 |

**Peak Flow (Qmax)**

Applying the peak factor to the average daily flow rate and converting to gpm will yield the peak flow to be used as the basis of design.

$Q_a$ /1440 x PF = $Q_{max}$ where:

$Q_a$ = Ave daily flow (gpd)
PF = Peak factor
$Q_{max}$ = Peak Flow (gpm)

***Example 1***

If the design firm provides the average daily flow based on local water records and recommends a peaking factor, both should be used as the basis for design.

| | |
|---|---|
| Average daily flow rate: | 75 gpcd |
| Persons/house | 3.0 |
| # houses: | 400 |
| Peak factor: | 3.5 |

$Q_a$ = 75 gpcd x 3.5 per/hse x 400 hses = 105,000 gpd
PF = 3.50

$Q_{max}$ = 105,000 gpd/1440 x 3.50
= 255 gpm

***Example 2***

If the design firm does not suggest average daily flow rates and peaking factors, then the Ten State Standards should be used for both.

| | |
|---|---|
| Average daily flow rate: | 100 gpcd |
| Population (3.0 x 400): | 1200 |
| Peak factor | 3.75 |

$Q_a$ = 100 gpcd x 1200 persons = 120,000 gpd
PF = 3.75

$Q_{max}$ = 120,000 gpd/1440 x 3.75
= 313 gpm

**Infiltration**

The vacuum system is a sealed system that eliminates ground water infiltration from the piping network and the interface valve pits. However, ground water can enter the system as a result of leaking house plumbing or as a result of building roof drains being connected to the plumbing system. While vacuum systems have some inherent reserve capacity, significant amounts of homeowner Infiltration & Inflow (I&I) can result is severe system operating problems. For this reason, it is recommended that designers consider methods of eliminating ground water from plumbing systems during the design phase of a project rather than adding a homeowner infiltration component to the design flow.

**Velocity**
Tangential liquid velocities in the typical vacuum sewer are 15-18 fps, obviously well above the minimum required for self-cleaning. The high transport velocities suggest that the probability of blockages occurring is remote.

**Vacuum transport & Air/Liquid ratio's**
The system designer needs an understanding of the vacuum transport process. With the saw-tooth profile design concept (see box below), when no vacuum valves are operating, no sewage transport takes place. All sewage remaining in the sewers will lie in the low spots and minimal vacuum loss is experienced throughout the system when this condition exists.

Vacuum systems are designed to operate on two-phase (air/liquid) flows with the air being admitted for a time period twice that of the liquid. Open time of the AIRVAC valve is adjustable; hence, various air to liquid (A/L) ratios are attainable.

The ability of the vacuum main to quickly recover to the same level of vacuum that existed prior to the cycle, commonly referred to as "vacuum recovery", is very important in vacuum sewer design. Vacuum recovery is a function of line length, pipe diameter, number of connections, and the amount of lift in the system.

## THE SAWTOOTH PROFILE DESIGN CONCEPT

The sawtooth profile design assumes that an open passage of air between the vacuum station and the interface valves is maintained throughout the piping network, providing the maximum differential pressure at the interface valves to insure maximum energy input to the vacuum mains.

When the liquid comes to rest at the base of various lifts, it does not come in contact with the crown of the pipe and therefore does not seal the pipe. Should the lift be sealed for any reason, liquid is suspended on the downstream side of the lift and an associated vacuum loss is incurred.

The AIRVAC design philosophy includes an accounting of all lifts for all flow paths within a system and the associated potential vacuum loss incurred. The static loss limit assures that sufficient vacuum will be available for valve operation in the event of a system upset such as 100% lift saturation.

(AIRVAC, 2005)

The AIRVAC 3-inch valve is rated for 30 gpm, *assuming sufficient vacuum levels exist at the valve location*. This capacity is achieved when the valve cycles 3 times in a minute, with each cycle discharging 10 gallons. The length of one complete valve cycle is about 6-8 seconds, consisting of 2-3 seconds for the liquid, followed by 4-5 seconds of air. During this time, vacuum levels at the valve location temporarily drop as energy is used to admit the sewage into the main line. The valve then “rests” before the next cycle begins, which occurs when another 10 gallons accumulates in the sump. Vacuum recovery occurs during the valve-closed time as the vacuum level in the main is restored. It is very important to note that the 30 gpm **rated capacity of the valve** is not to be confused with the **recommended design capacity of the valve pit** (see Table 2).

**TABLE 2**

Recommended Maximum Design Flow Rates
For Valve Pits

| Pit Type | Recommended Peak Flow (gpm) | Maximum * Peak Flow (gpm) |
|---|---|---|
| Standard valve pit | 0.5 - 1.5 gpm | 3 gpm |
| Single Buffer Tank | 3.1 - 15.0 gpm | 30 gpm |
| Dual Buffer Tank | 15.1 - 30.0 gpm | 60 gpm |
| Consult Manufacturer | > 30.0 gpm | > 60 gpm |

* Depending on static and friction loss, the overall amount of peak flow entering the system through buffer tanks and the exact location of the buffer tank, it may be possible to size a particular valve pit or buffer tank with the upper limits shown in this column. Consult the manufacturer for guidance.

When vacuum levels decrease, there is a corresponding decrease in the valve capacity. This is due to the lower pressure differential that exist which results in less available energy and hence slower evacuation times. A low vacuum condition can occur when a larger than usual amount of flow enters the main, followed by a relatively small amount of air, resulting in a low air-to-liquid ratio. This could occur, for example, at a buffer tank where high discharge rates are common and where repeated firing of the valve over short periods of time may not allow sufficient vacuum recovery. The net result would be progressively decreasing pressure differentials and lower evacuation rates. For this reason, a system with nothing but high-flow inputs is not recommended (see box below).

## SITUATION TO AVOID!
## USING VACUUM AS AN INTERCEPTOR SEWER

The idea of collecting wastes by gravity and then using vacuum as an interceptor sewer is intriguing; however, this will not work very well, if at all. An insufficient air to liquid (A/L) ratio and subsequent waterlogging will result.

Experience has shown that liquid transport in a vacuum system works best when there are many small energy inputs (i.e. – valve pits) located at various points throughout the system. Conversely, the worst liquid transport characteristics occur where there is a single, large flow input located at the extreme end of a line.

***Bottom line: Vacuum sewers are intended to be a form of collection, not transmission.***

(AIRVAC, 2005)

### Odors and corrosion

There are few odor problems reported with vacuum sewers. There are three contributing factors responsible for this: 1) the system is sealed, 2) air is introduced and not discharged and 3) detention times are short.

The entire system, from the valve pit setting to the vacuum station, is sealed. The valve pit sump containing the sewage is tested for tightness both at the factory and in the field after installation. The piping system contains no air releases. The collection tank at the vacuum station, into which all of the sewer mains empty, is a vacuum-tight vessel.

There is a large amount of air introduced into the system at each valve pit setting, which aids in the prevention of septic sewage through the violence imparted within the collector pipes.

The typical valve cycle volume is about 10 gallons. This small volume results in frequent valve cycles. Once in the main, the sewage travels at velocities in excess of 15 fps. Also, the relative liquid to air volume in the main is quite low. These factors result in a short detention time, which also aids in the prevention of septic sewage.

A possible exception to the above discussion on odors can occur when concrete buffer tanks are used. Unlike the fiberglass settings, these tanks are open from the sump to the top of the lid. Operating personnel must be careful of sewer gas buildup in these tanks when performing maintenance, although the volume of sewage present in the tank usually may not be large enough to produce dangerous levels of hydrogen sulfide. Also, these types of tanks typically are used to attenuate large flows, allowing the sewage more time to turn septic.

All of the system parts in contact with sewage are made of corrosion resistant materials.[1] As such; corrosion has not been a problem in vacuum sewers.

The accumulation of grease is a cause for concern in a vacuum station just like it would be in a conventional lift station. Grease builds up on level controls and on the sides of the vacuum collection tank. Grease traps are typically required in applications such as restaurants to minimize these problems.

Grease has not presented problems in vacuum sewer mains. When the sewage is evacuated from the sump, the suction generally pulls floatable grease into the vacuum mains. Since the sewage moves through the mains at high velocities, there is little opportunity for grease in the sewer to build up in the system to any level that could cause a blockage.

**Static and friction losses**

Vacuum systems are designed not to exceed 13 ft of static loss nor 5 ft of friction loss. This is a deviation from the early system design where the sum of the static and friction losses could not exceed 13 ft. These two losses are now considered independently.

The theory behind the 13 ft static loss is simple. Normally, the vacuum pumps are set to operate at 16-20 in. of Hg of vacuum. The minimum vacuum of 16-in. Hg results in a total available head loss of 18 ft; 5 ft of this head loss is required to operate the vacuum valve, thus leaving 13 ft available for sewage transport (Figure 4).

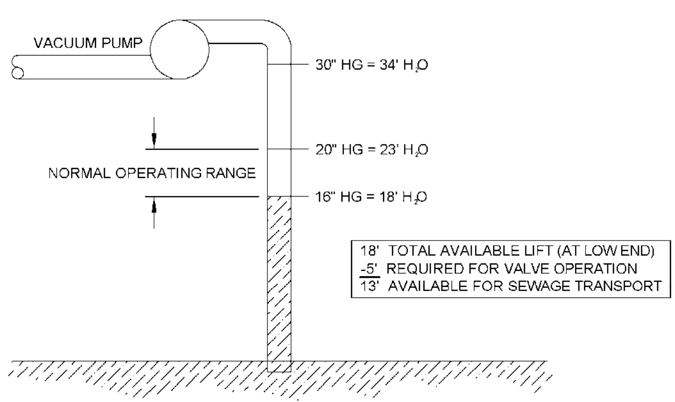


Figure 4
Vacuum Lift Capability
(Courtesy AIRVAC)

Static losses are those incurred by using lifts, or vertical profile changes. Profile changes are accomplished by using two 45-degree fittings joined by a section of pipe. For efficient use of the energy available, profile changes should be as small as possible. Numerous lifts are recommended over one large lift (AIRVAC, 2005). Table 3 shows the recommended lift height for various pipe sizes.

**Table 3**

Recommended Lift Height

| Pipe Diameter (in) | Lift Height (ft) |
|---|---|
| 3 | 1.0 |
| 4 | 1.0 |
| 6 | 1.5 |
| 8 | 1.5 |
| 10 | 2.0 |

Static losses are calculated by subtracting the pipe diameter from the lift height (Figure 5).

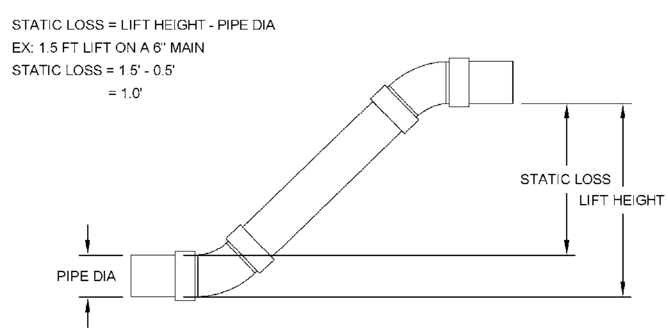


Figure 5
Static Loss Determination
(Courtesy AIRVAC)

Friction losses are only calculated for sewers that are laid on a downward slope between 0.20% and 2.0% and are cumulative for each “flow path” from the furthest valve on the line to the vacuum station. Friction losses in sewers installed at greater than 2.0% percent are ignored. Friction loss charts for SDR 21 PVC pipe and a 2:1 air/liquid ratio have been developed by AIRVAC and are contained in their Design Manual[1] (AIRVAC, 2005).

**Situations to avoid**

Vacuum sewers are a very reliable, cost-effective alternative when designed for the appropriate conditions. However, there are certain situations that should be avoided as they may result in less than desirable results. Examples of these are:

- Using vacuum as an interceptor sewer (see Page 12)
- Long distances with no connections (see Page 17)
- Over-use of buffer tanks (see Page 28)

These situations are discussed in text boxes in the above referenced sections of this manual.

**Effects of water conservation**

Vacuum sewer systems have been used in areas that practice water conservation measures. There have been no specific studies done regarding water conservation and its effect on a vacuum system. However, to date, there have been no negative reports of poor performance due to water conservation from any vacuum system operators.

The general thinking is a vacuum system can more easily handle a wastewater stream with less liquid than can a gravity system, which requires a certain amount of liquid to carry the solids. The major reason for this is the additional force, i.e., the pressure differential that assists the natural gravity flow.

The best evidence of this can be seen in the cruise ship industry, where water conservation goes beyond the low-flush toilets used in residential situations. For many years, cruise ships have successfully used internal vacuum systems with vacuum toilets that use as little as 1 quart of water.

### *B. Mains and Service Lines*

The major components of the vacuum-piping network are defined below and are depicted in Figure 6.

| | |
|---|---|
| Main line: | Larger diameter trunk lines that enter the vacuum station |
| Branch line: | Smaller diameter lines that connect to the vacuum main |
| Service lateral: | 3" vacuum line that connects the valve pit to the vacuum main |
| Valve pit: | Point of connection for customer |
| Vacuum station: | Heart of system where vacuum is produced and sewage is collected |

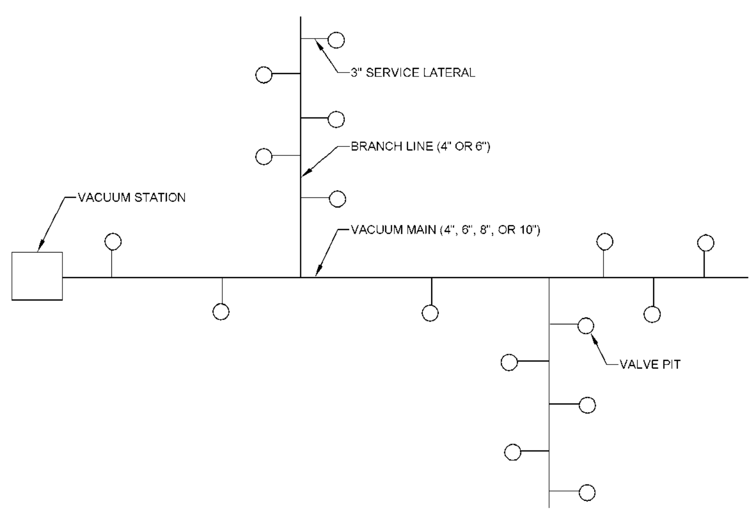


Figure 6
Major Components of a Vacuum System: collection piping
(Courtesy AIRVAC)

## Geometry and Sizing

The geometry of a vacuum sewer system is similar to that of a water distribution system. Rather than looped, however, it is normally designed in a tree pattern.

The length of vacuum mains is generally governed by two factors. These are static lift and friction losses, which were previously discussed.

Due to restraints placed upon each design by topography and sewage flows, it is impossible to give a definite maximum line length (length from vacuum station to line extremity). In perfectly flat terrain with no unusual subsurface obstacles present, a length of 10,000 ft can easily be achieved. With elevation to overcome, this length would become shorter. With positive elevation toward the vacuum station, this length could be longer. As an example, one operating system has a line that, from the vacuum station to the line extremity, exceeds 16,500 ft. in length.

The use of Horizontal Directional Drilling (HDD) could result in significantly shorter lines, as the shallowest slopes that are currently attainable with HDD are 0.50% rather than the 0.20% normally used. See Pages 51 & 52 for a more detailed discussion on this subject.

Another important consideration is the location of the valve pits along the vacuum main. Designers should avoid layouts that result in long stretches with no connections. Lack of valve pits, which act as energy inputs to the system, could have a detrimental effect on system hydraulics (*see box below*).

**SITUATION TO AVOID!**
**LONG DISTANCES WITH NO CONNECTIONS**

Occasionally an engineer will face a situation where there is a long pipe run with no house connections. This is a situation to avoid, as poor liquid transport characteristics could result.

Movement of liquid within the vacuum main depends on differential pressure. The differential is created when a vacuum valve opens and allows atmospheric air to enter a vacuum main that is under a negative pressure. The only place this can happen is where a vacuum valve exists.

Although most view the valve pit as simply a connection point for the customer, the designer views this as an "energy input" location. The more energy inputs along a given vacuum main, the better the system operates. Conversely, as fewer energy inputs exist, the transport characteristics become poorer.

(AIRVAC, 2005)

New developments, where many lots may initially be vacant, require special consideration. For these cases, it is suggested that the valve pit, less the valve, be installed to each lot at the same time the vacuum mains are installed. Should they be needed, one or more Electronic Air Admission Control (EAAC) valves could be installed at strategic pit locations along with a timer (see discussion on EAAC on page 36) to actuate the valve to impart the necessary air and energy to the piping network.

There are three (3) major items for the designer to consider when laying out a vacuum system:

> **Multiple service zones:** By locating the vacuum station centrally, it is possible for multiple vacuum mains to enter the station, which effectively divides the service area into zones. This results in operational flexibility as well as service reliability. With multiple service zones, the operator can respond to system problems, such as low station vacuum, by analyzing the collection system on a zone by zone basis to see which zone has the problem. The problem zone can then be isolated from the rest of the system so that normal service is possible in the unaffected zones while the problem is identified and solved.
>
> **Minimize pipe sizes:** By dividing the service area into zones, the total peak flow to the station is also spread out among the various zones, making it possible to minimize the pipe sizes.
>
> **Minimize static loss:** Static loss is generally limited to 13 ft. Items that result in static loss are increased line length, elevation differences, utility conflicts and the relationship of the valve pit location to the vacuum main (*see box below*).

Vacuum sewer design rules have been developed largely as a result of studying operating systems. Important design parameters such as minimum distance between lifts, minimum slopes, slopes between lifts, etc. are contained in AIRVAC's 2005 Design Manual[1].

**MINIMIZING STATIC LOSS**

Static loss is generally limited to 13 feet. Items that result in static loss are:

***Line length:*** In perfectly flat ground, lifts are made to keep the vacuum main at the same invert level. Every lift has an associated loss depending on the lift height and pipe diameter. By locating the vacuum station centrally, the length of longest line can be kept to a minimum, resulting in the lowest possible vacuum loss due to lifts.

***Elevation differences:*** To overcome elevation differences will also require lifts. While the amount of lift needed to overcome a given elevation difference depends on the pipe sizes, the actual lift height, etc., in general the lift loss is similar to the actual elevation overcome.

***Utility conflicts/canal crossings:*** To cross under utilities and then return the pipe to minimum depth requires lift. Crossing over the utility, if possible, will minimize or even totally eliminate lift.

***Relationship of valve pit to main:*** There are situations where the elevation of a house is lower that the road elevation. In this case the valve pit will have to be located such that gravity flow from the house is possible. This usually will result in lift in the service line between the valve pit and the vacuum main.

***Tip:*** ***A key to minimizing vacuum loss is to avoid combinations of the above.***

(AIRVAC, 2005)

Based on in-house hydraulic testing and an adaptation of the Hazen-Williams equation, AIRVAC developed a table showing the recommended maximum flow rates as well as the absolute maximum flow rate for a given pipe size. Table 4 shows these recommendations.

**Table 4**

Recommended & Absolute Maximum
Flow Rates for Various Pipe Sizes

| Pipe Diameter (in) | Recommended Maximum Flow Rate (gpm) | Absolute Maximum Flow Rate (gpm) |
|---|---|---|
| 4 | 40 | 55 |
| 6 | 105 | 150 |
| 8 | 210 | 305 |
| 10 | 375 | 545 |

Line size changes are made when the cumulative flow exceeds the maximum recommended design flow for a given line size. As a practical matter, most designers will make this transition at a logical geographic location such as a street intersection.

The values in Table 4 should be used for planning purposes or as a starting point for the detailed design. In the latter case, estimated site-specific flow inputs along with the friction tables should be used in the hydraulic calculations. A correctly sized line will yield a relatively small friction loss. If the next larger pipe size significantly reduces friction loss, the line was originally undersized.

The maximum number of houses served by a given line size is shown on Table 5, which assumes the peak design flow for 1 house is 0.50 gpm.

**Table 5**

Maximum Number of Houses Served for Various Pipe Sizes
(based on Rec'd Maximum Flow using
a peak design flow of 0.50 gpm/house)

| Pipe Diameter (in) | Maximum Number of Homes Served |
|---|---|
| 4 | 80 |
| 6 | 210 |
| 8 | 420 |
| 10 | 750 |

**Routing**

An advantage to the use of vacuum sewers is that the small diameter PVC pipe used is flexible and can be easily routed horizontally around obstacles. The feature allows vacuum sewers to follow a winding path as necessary.

In most cases, vacuum sewer mains are located outside of and adjacent to the edge of pavement and approximately parallel to the road or street, which reduces the expenses of pavement repair and traffic control. In areas subject to unusual erosion, the preferred location is often within the paved area. Some municipalities also favor installation within the paved area since subsequent excavation is less likely and more controlled (via permit application only), and therefore a location more protected from damage. However, community disruption potential during construction and maintenance for this approach increases substantially.

With two or more houses sharing one valve pit, overall system construction costs can be significantly reduced, resulting in major cost advantage.  In some circumstances, however, this approach may require the main line to be located in private property, typically in the back yard.  There are two disadvantages to this type of routing.  First, it requires permanent easements from one of the property owners, which may be difficult to obtain.  Second, experience has shown that multiple house hookups can be a source of neighborhood friction unless the pit is located on public property.  The designer should carefully consider the tradeoff of reduced costs to the social issues prior to making the final routing decision.

Vacuum sewers are normally buried with a cover of 36 inches. Frost penetration depths usually dictate the depth of burial in colder climates.  In the northern U.S., they are often placed at a depth of 4-5 ft. Even though line freezing is a concern with most engineers, it is not a problem with vacuum mains since retention time in small diameter lines is relatively short and turbulence is inherent.

The separation of vacuum sewers from water mains often requires the vacuum sewer be buried deeper than would be required for other reasons.  Horizontal and vertical separation requirements are dictated by State Agencies and vary from state to state. At least one state, Florida, has allowed for smaller separation of vacuum and water lines with the idea that, if both the vacuum main were broken, air and water would be pulled into the vacuum sewer rather than raw sewage leaking out.

Profiles of the mains should always be shown on the plans.  Slopes, line sizes and lengths, culvert and utility crossings, inverts, and surface replacements are typically shown on the profiles.

Culvert and utility crossings often dictate numerous variations in the depth of burial of vacuum sewer mains, with many resulting sags and summits in the pipeline profile.  Unlike pressure mains, where air accumulates at a summit requiring an air release valve, high points in the profile do not affect vacuum sewers.  The sags; however, do add lift to the system.  If not designed and constructed properly, sags may trap sewage at low flow periods blocking off the vacuum in the low part of the sewer.

**TECHNOLOGY IMPROVEMENT**
**O-RING GASKET PIPE FOR VACUUM USE**

Early vacuum systems were constructed using solvent welded joints.  Several factors relating to gluing of pipe, including human error, led to problems with leaking joints.

In the mid-1980's most designers began using standard O-ring PVC pipe that is equipped with a special double-lipped gasket. The number of main line leaks has deceased drastically as a result. Experience has proven this pipe to be economical to install, reliable to operate and easy to repair.

**Pipe Materials**
PVC thermoplastic pipe, typically Class 200, SDR 21 PVC, is normally used for vacuum sewers. In some installations, MDPE, HDPE and ABS have been successfully used. In certain cases, DIP has also been used, assuming the joints have been tested and found suitable for vacuum service. To reduce expansion-and-contraction-induced stresses, flexible elastomeric joint pipe is preferred. If solvent-welded joint pipe is used, the pipe manufacturer's recommendations for installation regarding temperature considerations should be followed.

**Service Laterals (Valve pit to vacuum main)**
Vacuum service laterals connect the vacuum main to the valve pit. Service laterals typically are 3-in. in diameter. As with the vacuum sewer mains, Class 200, SDR 21 PVC pipe typically is used for the service laterals with rubber O-ring fittings preferred.

Service laterals should be located distant from potable water lines to reduce the possibility of cross contamination. If possible, they should also be distant from other buried utilities to reduce the possibility of damage caused by subsequent excavations for maintenance or repair of those utilities.

AIRVAC recommends all connections to the main be made "over the top" by using a vertical wye fitting and a long radius elbow (Figure 7). Due to the restraints placed upon the depth of the mainline sewers by the connecting service laterals entering "over the top," engineers should consider the minimum ground cover required on these connections at the design stage. The invert spacing can be reduced by rolling the wye fitting to a 45 degree angle. This method is acceptable, provided the invert of the connecting pipe is at least 2 inches above the crown of the main.

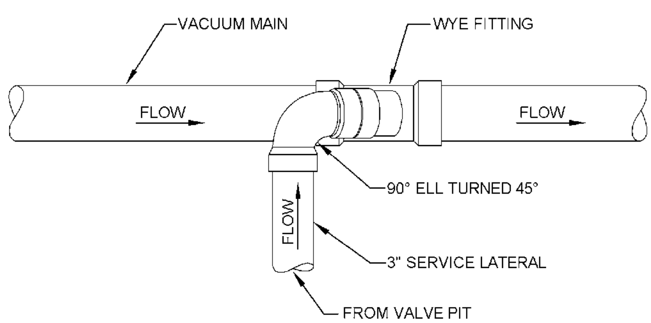


Figure 7
"Over the Top" service lateral connection
(Courtesy AIRVAC)

### *C. Valve Pit Settings and Building Sewers*

The major components relating to the valve pit are defined below and are depicted in Figure 8 This integral valve pit arrangement is an improvement over the early side-by-side valve pit arrangement (*see box below*).

| | |
|---|---|
| Pit cone: | upper chamber that houses the vacuum valve |
| Sump: | lower chamber that accepts sewage from the building sewer |
| Pit bottom: | physical separation between sump & pit cone |
| Vacuum valve: | 3" interface valve (normally closed) |
| Suction line: | 3" line used to evacuate the sump |
| Sensor line: | 2" line used to transfer rising sump pressure to valve controller |
| Stub-out: | Short piece of pipe that extends to customer's property |
| Service lateral: | 3" vacuum line that connects valve pit to the vacuum main |
| Flotation collar: | Fiberglass collar to keep valve pit from floating |
| Valve pit cover: | Protective traffic rated lid for pit (not shown) |
| In-sump breather: | Device that allows a small amount of atmospheric air from the sump to close the valve controller, while protecting it from unwanted water (not to be confused with the larger amount of air needed for sewage transport supplied by the air-intake). |

## TECHNOLOGY IMPROVEMENT
## INTEGRAL VALVE PIT

Early (1970's) valve pits had a side-by-side arrangement with rigid piping connecting the two chambers. Two problems occurred: 1) problems with differential settlement led to pipe breaks and ultimately to vacuum leaks and 2) the glued, rigid connecting piping frequently failed also causing vacuum leaks.

The current top/bottom arrangement does not include this connecting piping. This eliminated contractor error on two fronts: compaction of the pits and gluing of the connecting pipe-fittings. (AIRVAC, 2005)

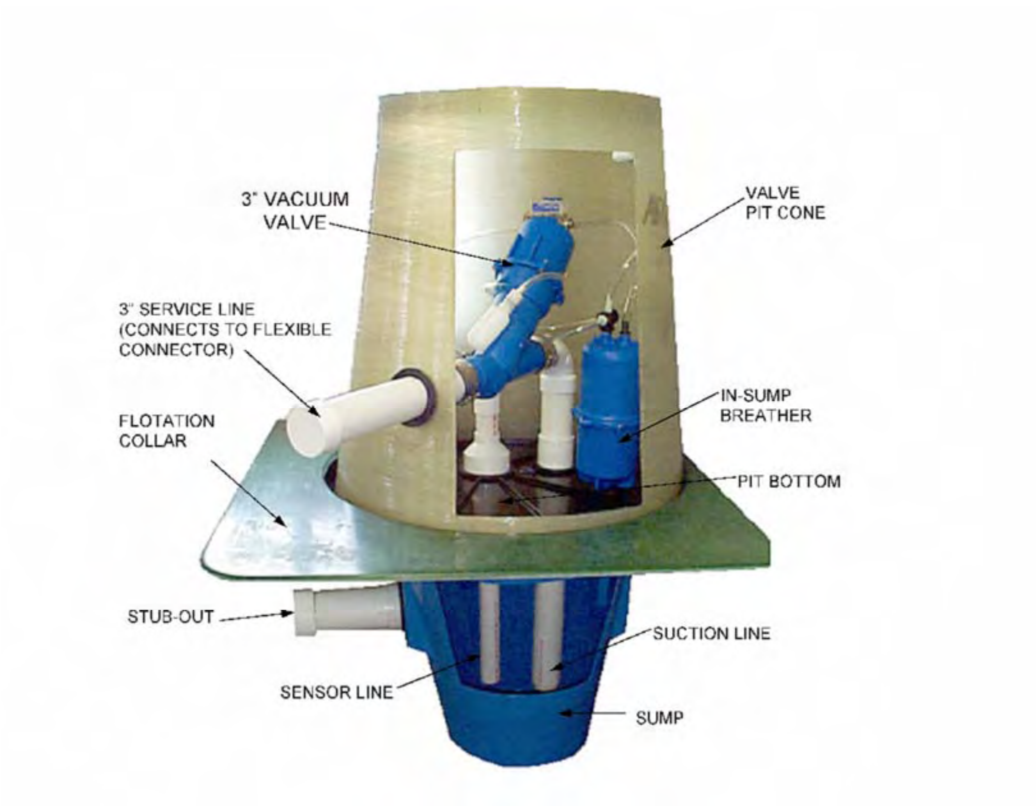


Figure 8
Valve Pit setting – major components
(Courtesy AIRVAC)

## Valve Pits

Figure 9 shows a pre-manufactured, fiberglass type of valve pit setting, which is by far the most common. This type of setting is composed of four main parts; the bottom chamber (sump), the top chamber (valve pit), the plate that separates the two chambers (pit bottom), and the lid.

Wastes from the home are transmitted via the building sewer to the stub-out. The stub-out inlet enters the sump 18 inches above the bottom. Holes for the building sewers are field cut at the position directed by the engineer. Various valve pit arrangements are available to accommodate varying depths of service (5 feet to 10 feet). The shallower arrangements would be used in areas where high ground water or poor soils exist and depth of the building sewers is very shallow.

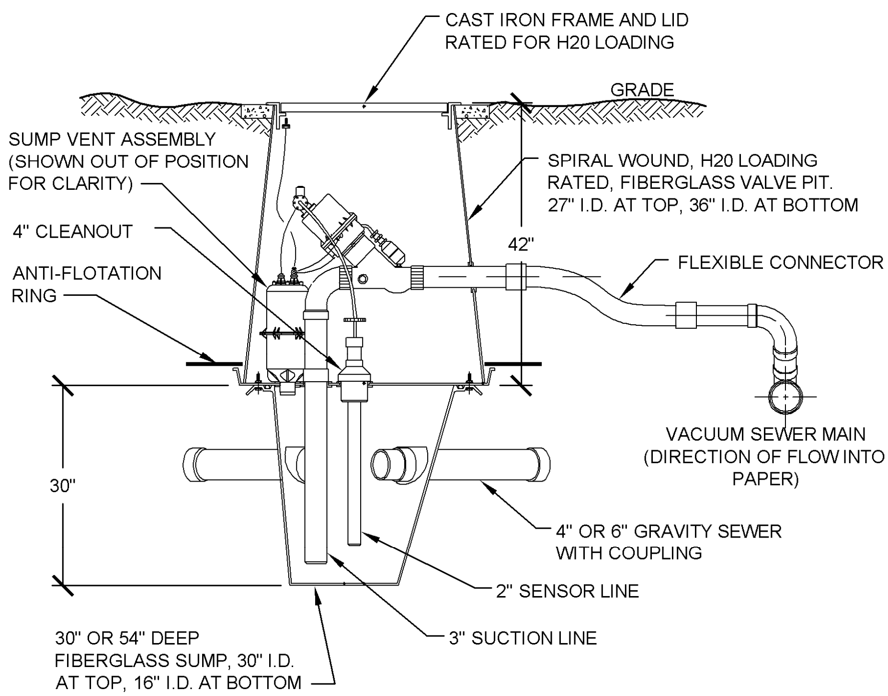


Figure 9
Typical Fiberglass valve pit setting
(Courtesy AIRVAC)

Up to four separate building sewers can be connected to one sump, each at 90 degrees to one another. However, this is rarely done as property lines considerations and other factors may render this impractical. By far, the most common valve pit sharing arrangement is for two adjacent houses to share a single valve pit (AIRVAC, 2005)

Some have attempted to reduce costs by having additional houses sharing a single valve pit. Experience has shown that, while this may appear to be viable on paper, many times it is not achievable during construction. And, even if it is, the perceived cost savings does not always materialize. Longer runs of gravity laterals are required which results in deeper valve pits needed to accommodate this. Also, the additional 2 or 3 ft of excavation of not just the pit, but the gravity laterals as well, may result in extensive dewatering.

In certain cases, such as the existence of a cul-de-sac or when small lots with short front footage exists, it may be possible to serve 3 or even 4 houses with a single valve pit; however, all other design factors must be considered.

**Buffer tanks**

Buffer tanks are typically used for schools, apartments, nursing homes, and other large volume users. Their use should be limited to users where service at only one or two locations is possible (e.g.: a commercial user). They should not be used where individual valve pits could otherwise be employed (AIRVAC, 2005).

Buffer tanks are designed with a small operating sump in the lower portion, with additional emergency storage available in the tank. These types of settings are typically constructed of 4-ft diameter concrete manhole sections, with the bottom section having a pre-poured bottom with an 18-in diameter sump (Fig 10).

It is very important that all joints and connections be watertight to eliminate ground-water infiltration. Equally important is the need for a well-designed pipe support system, since these tanks are open from top to bottom. The support hardware should be of stainless steel and/or plastic.

Considering the discussion on pages 9 &10, a lower evacuation rate of 15 gpm is recommended for buffer tank sizing. This lower rate assists proper vacuum recovery. Table 2 shows the recommended maximum design flows for buffer tanks.

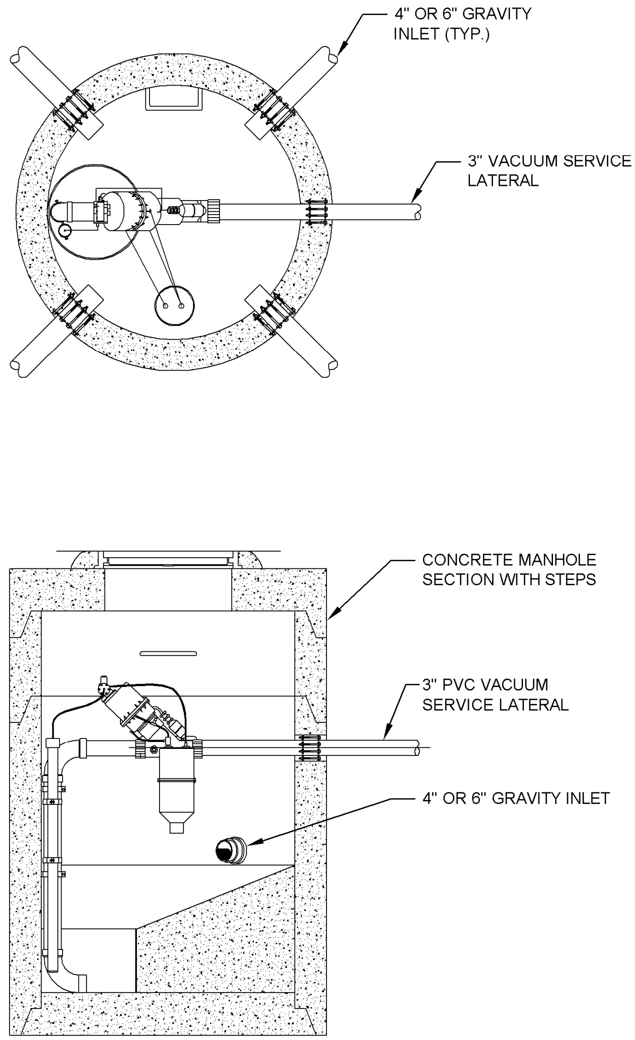


Figure 10
Concrete Single Buffer Tank
(Courtesy AIRVAC)

## SITUATION TO AVOID!
## OVERUSE OF BUFFER TANKS

AIRVAC does not recommend using buffer tanks on a widespread basis. Much depends on the location of the buffer tank itself, the length of travel to the vacuum station, the amount of lift in the system, and how many other buffer tanks there are in close proximity. In general, the closer to the station, the less lift, and the fewer other buffer tanks that exist, the better chance there is of the system operating successfully.

Because of the possibility of water-logging, the AIRVAC Design Manual limits the use of buffer tanks as follows: **1)** ***No more than 25% of the total peak flow of the entire system shall enter through buffer tanks*** and **2)** ***No more than 50% of the total peak flow of a single vacuum main (i.e. – flow path) shall enter through buffer tanks.***

(AIRVAC, 2005)

A dual buffer tank is similar to a single buffer tank, with the exception that it is larger to accommodate two vacuum valves (Figure 11). These tanks typically utilize 5-ft diameter manhole sections. Dual buffer tanks may also be used if the single buffer tank does not have the capacity for the large flows.

AIRVAC recommends that a specific "not to exceed" percentage of the total peak flow be contributed to the vacuum mains from buffer tanks (AIRVAC, 2005) (*see Situations to Avoid box*). This design criterion was established to ensure that an adequate air-to-liquid ratio is maintained in any section of the vacuum mains, thereby preventing the mains from becoming water-logged and for the timely recovery of vacuum conditions throughout the system.

The amount of flow entering via a buffer tank(s) at a single location is also important. This is dependent on the location of the buffer tank in the piping network. AIRVAC's Design Manual[1] provides some general guidelines regarding this.

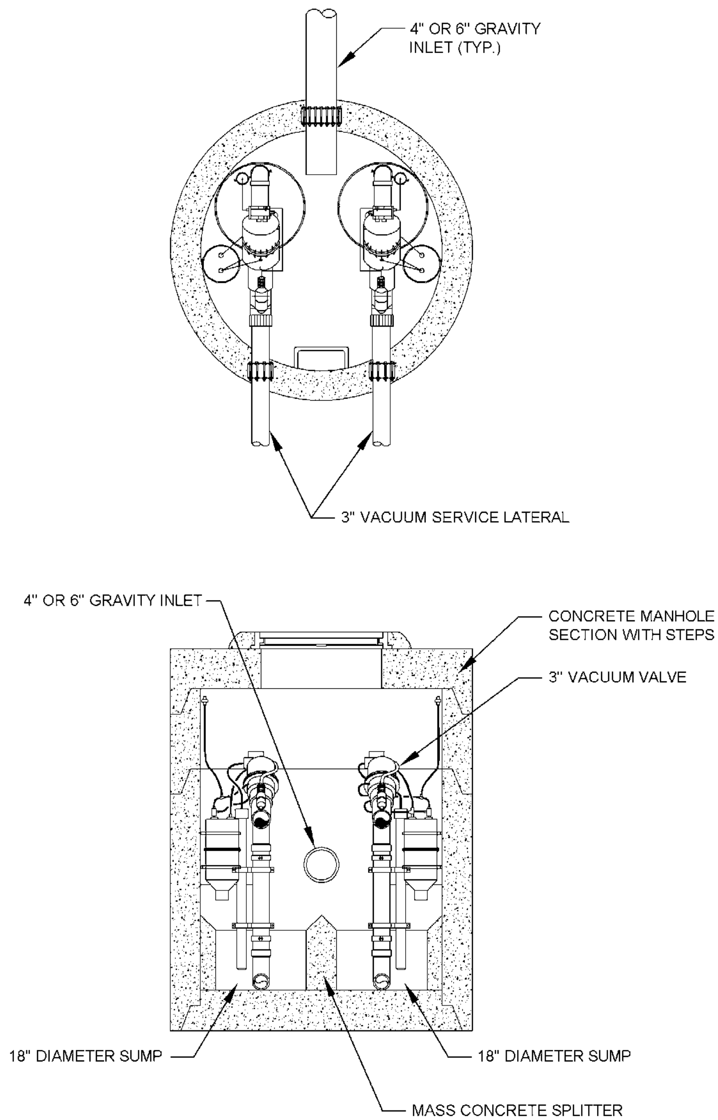


Figure 11
Concrete Dual Buffer Tank
(Courtesy AIRVAC)

## Stub-outs

Typically the valve pit setting will include a short piece of pipe extending from the sump to the property line. This short section is called a “stub-out” (see Figure 8). The stub-out is used to minimize the risk of damage to the fiberglass valve pit during homeowner connection to the system.

Pressure rated Sch 40 or SDR 21 PVC pipe is recommended for the stub-out since this type of pipe has an outside diameter (OD) that matches the grommet provided in the sump opening. A tight fit at this joint prevents the entrance of I/I into the sump.

## Building Sewers

The term building sewer refers to the gravity flow pipe extending from the house to the valve pit setting. The building sewer connects to the stub-out. In many cases, state or local authorities regulate installations of building sewers. The Uniform Plumbing Code is often referenced.

For residential service, the building sewer should be 4-in and slope continuously downward at a rate of not less than 0.25-in/ft (2-percent grade). Line size for commercial users will depend on the amount of flow and local code requirements.

Bends should be avoided in building sewers, and a cleanout used for each aggregate change in direction exceeding 57 degrees. If the building sewer piping network does not have a cleanout within it, one should be placed outside and close to the home. Some agencies prefer having a cleanout at the dividing line where agency maintenance begins. In most cases this would be at the end of the 6-ft stub-out pipe.

Infiltration via leaking building sewers has been common, as has the connection of roof and yard drains (inflow). A quality inspection during homeowner connection is advised to determine if these situations exist. If so, steps should be taken to require their elimination prior to final homeowner connection.

As was the case with the stub-out pipe, pressure rated Sch 40 or SDR 21 PVC pipe is also recommended for the building sewer. Should the air-intake be blocked and the vacuum valve fail in the open position at the same time, the building sewer could see the full system vacuum of 20-in. of Hg. Therefore, the existing building sewer may need to be replaced at most existing houses.

AIRVAC’s 2005 Design Manual[1] contains specific information regarding recommended pipe types for both the stub-out pipes as well as the building sewers.

**Backwater valves**
Vacuum valves almost always fail in the open position. In this failure mode, the homeowner is not affected, as the contents of the sump will continue to be emptied as long as sufficient vacuum levels remain. It is rare that a vacuum valve fails in the closed position due to a physical defect or problems internal workings of the valve itself. It is possible, however, that the valve does not open because of insufficient vacuum. A broken or leaking vacuum main or some other system problem that results in a low vacuum condition could cause this. In this case, sewage backup into the home may occur.

Some entities prefer the use of backwater valves on the building sewer in order to provide sewage backup protection, especially for houses that share a valve pit when the houses are at different elevations. For the typical "normally closed" type backwater valve, positioning is critical. If not installed between the house and the air intake pipe, the vacuum valve will not operate. The preferred type of backwater valve is one designed to be in the "normally opened" position. Location is not an issue for this type of valve and they have proven to have superior performance when used in a vacuum system.

**Air-intake**
An air-intake, consisting of 4-in PVC pipe, fittings and a screen (Figure 12), is required for each building sewer. Its purpose is to provide a sufficient amount of air to enter into the vacuum main via the building sewer and valve pit to act as the driving force behind the liquid that is evacuated from the sump. Since plumbing vents allow air out, while the air intake draws air in, the air intake is not considered to be a component of the customer's plumbing vent system.

Most plumbing code enforcement entities require the air-intake to be located against a permanent structure, such as the house or a wall. Because of the variation in local code enforcement agencies, the design engineer and governing utility should be aware of the plumbing code requirements and inform the homeowner prior to the installation of the required sewer connection.

The house vent may not be used in place of an air intake. While it may provide the necessary air, its location could result in the house plumbing traps being evacuated during a valve cycle (AIRVAC, 2005). For this reason, the air-intake must be located downstream of the last house plumbing trap. Also, the use of a check valve within the air-intake itself is not recommended as this too will result in problems with the traps inside the house.

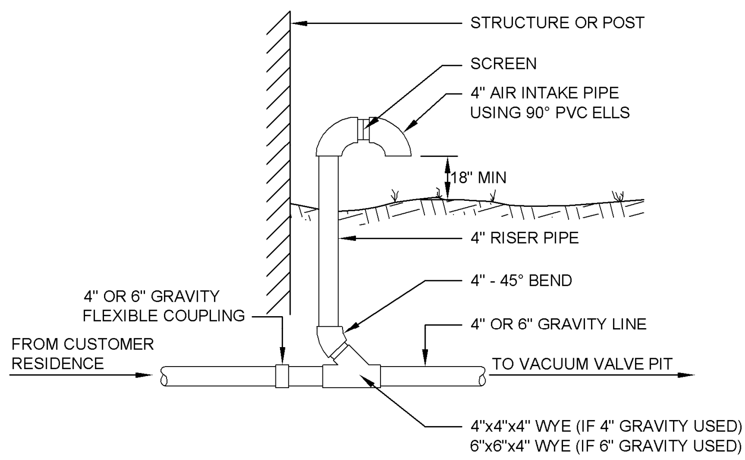


Figure 12
Air-intake
(Courtesy AIRVAC)

**Appurtenances**

The designer should perform buoyancy calculations to see if anti-floatation collars are needed to prevent the valve pit from floating. Until recently, anti-flotation collars consisted of concrete rings. These concrete rings required care be taken during the valve pit installation as poor bedding and backfill could lead to differential settlement around the valve pit causing the heavy concrete collars to shift. The result can be damaged valve pits and/or broken vacuum lines near the valve pit.

Recent systems have used fiberglass anti-flotation collar (see Figure 8) that fit around the tapered valve pit and rely on soil burden to keep the pit from floating. The fiberglass collars not only eliminate the settlement problem, but are much less labor intensive to install than the concrete collars.

Safety is also a concern with the old style concrete rings. Concrete collars have metal lifting rings used during the initial placement of the collar. There have been reports of these lifting rings later failing after being exposed to corrosive underground conditions. Not only can the valve pit be easily damaged should the collars later be removed, but the workers are also vulnerable to injury during this process. Again, the lightweight fiberglass collars eliminate this problem.

### *D. Vacuum Valves*

There are 2 different types of vacuum valves: the piston-type and the diaphragm-type. While both types are used in Europe and other countries, virtually all U.S. installations use the piston-type manufactured by AIRVAC. For that reason, the discussion that follows will concentrate on the piston-type valve.

**Vacuum Valve**

The AIRVAC valve is vacuum operated on opening and spring assisted on closing. System vacuum ensures positive valve seating. The valves have a 3-in full-port opening, are made of glass filled polypropylene and have stainless steel shafts, Delrin bearings and elastomer seals (AIRVAC, 2005). All materials of the valve are chemically resistant to normal domestic sewage constituents and gases.

Vacuum sewer design follows the industry standard that advocates the ability to pass a 3" solid through any part of a sewage collection system. Some plumbing codes have provisions that to prohibit restrictions less than 3" downstream of any toilet. For these reasons, a minimum valve size of 3" is recommended.

The driving force in a vacuum system is the pressure differential that exists between atmosphere and vacuum in the system. This differential occurs when the valve opens. As a result, the only place to impart energy in a vacuum system is at the valve itself. Since vacuum sewers have a limited amount of energy available, any loss through the valve further depletes this energy resulting in less available for transport within the pipeline. This is especially critical when one considers that this loss occurs at each valve and during each valve cycle. For this reason, it is important to use a vacuum valve with a high $C_v$ (flow coefficient) factor and hence, a low head loss through the valve. The $C_v$ factor is the flow rate in gallons per minute (gpm) which would yield a head loss of 1 psi.

**Controller/sensor**

The controller/sensor is the key component of the vacuum valve. The device relies on three forces for its operation: pressure, vacuum, and atmosphere. As the sewage level rises in the sump, it compresses air in the sensor tube. This pressure initiates the opening of the valve by overcoming spring tension in the controller and activates a 3-way valve. Once opened, the three-way valve allows the controller/sensor to take the vacuum from the downstream side of the valve and apply it to the actuator chamber to fully open the valve. The controller/sensor is capable of maintaining the valve fully open for a fixed period of time, which is adjustable over a range of 3 to 10 seconds. After the preset time period has elapsed, atmospheric air is admitted to the actuator chamber permitting spring assisted closing of the valve (AIRVAC, 2005).

The AIRVAC vacuum valve controller was designed to give consistent timing as set by the system operator. The AIRVAC valve pit was also designed so that a very repeatable, specific amount of liquid is withdrawn on each cycle (10 gallons). With a consistent amount of air and a specific amount of liquid, the air/liquid ratio is kept consistent.

During system startup AIRVAC personnel will set the valve-controller timing while explaining the reasoning as it applies to that system. In some circumstances a whole system or small portions of a system may be designed to operate at higher air to liquid ratios. In this case, the controller can be adjusted to stay open longer in specific high lift areas. The longer timing will keep system lifts cleared, preventing undesired vacuum loss. The ability to field adjust the A/L ratio by adjusting the controller timing has been cited by operators as a necessary feature.

The AIRVAC Slip Key is provided as standard equipment on the AIRVAC valve. The slip key allows the operator to remove and re-install the controller without having to unscrew bolts. This feature was a result of feedback from operators who expressed the desire to be able to more easily remove and replace the controllers.

**Breathers**

As discussed earlier, the controller requires a source of atmospheric air to the actuator chamber permitting spring assisted closing of the vacuum valve. Without this air, the valve will stay in the open position. Two types of breathers have been used: external and in-sump breathers.

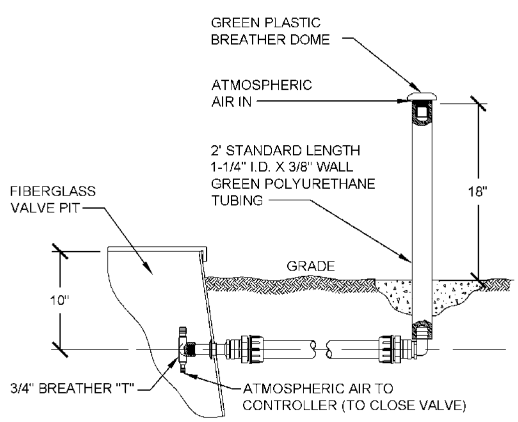


Figure 13
Early system external breather
(Courtesy AIRVAC)

Almost all systems installed prior to 2000 used an external breather (Fig 13). While relatively reliable, external breathers had two items that required attention. First, the entire breather piping system from the dome to the connection at the controller must be watertight. Second, the piping must slope toward the valve pit setting. If not properly installed or maintained, the external breathers could allow water to be directly pulled in the controller, resulting in the valve failing in the open position.

While external breathers have been successfully used in many operating vacuum system, some problems with perceived aesthetics and vandalism have been experienced. And, the external breather was consistently cited by operators as the single largest contributor to valve failures via “water in the controller.” Because of this, most recent systems use the in-sump breather described below.

In the late 1990’s, AIRVAC patented a device that eliminated the external breather. This was called the “in-sump” breather (Fig 14). As its name implies, this device uses atmospheric air from the sump to close the valve controller, rather than from an external source. In the event of low vacuum conditions where the valve would not open, floats in the in-sump breather protects the controller from unwanted liquid.

With the in-sump breather, the installation of the homeowner's building sewer becomes more critical. A sag in the building sewer alignment will trap water and not allow the free flow of atmospheric air, an additional reason for redoing the building sewer at existing residences.

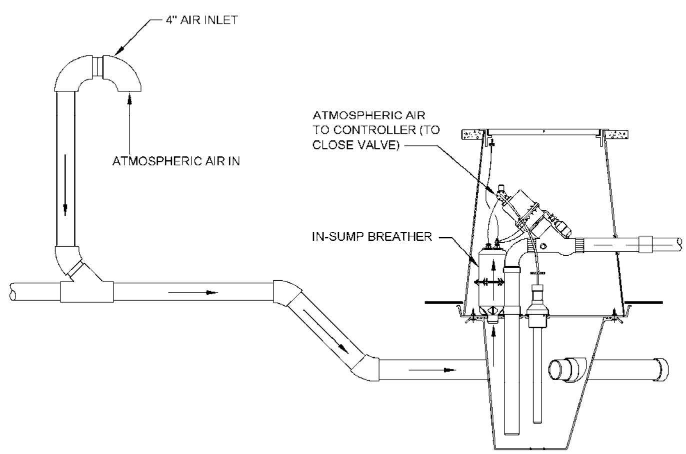


Figure 14
Recent system - in-sump breather
(Courtesy AIRVAC)

**Cycle Counter**

To monitor the number of valve cycles, a cycle counter can be employed. This device mounts directly on the vacuum valve or the valve pit wall. Cycle counters typically are utilized where a large water use is expected in order to determine if the valve is reasonably capable of keeping up with the flow or where an excessive amount of inflow or infiltration in the building sewer is suspected.

Some entities use the cycle counter as a metering device. Knowing the number of cycles and the approximate volume per cycle, one can estimate the amount of sewage through the vacuum valve over a given period. This would also allow a user to identify the amount of water used and discharged versus outdoor or other consumptive uses.

Others use the device as method of determining illegal storm connections. The flow through the valve can be estimated and compared to metered water use. From this, it is possible to determine the approximate amount of extraneous water entering the system.

**Electronic Air Admission Control (EAAC)**

The EAAC is an accessory for a typical 3" vacuum valve, adding separate battery operated controls (AIRVAC, 2005). This device monitors line vacuum and will open if vacuum falls below a pre-set limit for an extended period of time. The opening of this valve injects large quantities of atmospheric air to boost liquid through various lifts and downstream towards the vacuum station. The end result is an increase of available vacuum for valve operation.

The primary purpose of the EAAC is to improve the transport characteristics of a system that is already in operation. Occasionally, this device can be included as a design feature when static losses are slightly in excess of the recommended 13 feet. Since there are limits to the use of these devices, the vacuum manufacturer should be involved in the placement and parameters for their use.

### *E. Division Valves and Cleanouts*

Division valves are used on vacuum sewer mains much as they are on water mains. Plug valves and resilient-seated gate valves have both been successfully used, although most systems now use gate valves. Typical locations are at branch/main intersections, at both sides of a bridge crossing, at both sides of areas of unstable soil, and at periodic intervals on long routes. The intervals vary with the judgment of the engineers, but typically range from 1,500-2,000 ft.

The valves should be installed in a valve box conforming to local codes, with the operating nut extended to a position where it is accessible with a standard valve wrench. The valves should be capable of sustaining a vacuum of 24 in. Hg. Contract specifications should call for a certified test from an independent laboratory to verify this. Some more recent designs have included a gauge tap, located on the downstream side of each division valve (Figure 15). Its purpose is to allow periodic or troubleshooting vacuum monitoring by one person in the field.

Cleanouts, called access points in vacuum sewer terminology, have been used in the past. Their use is no longer recommended in systems with high valve pit density since access to the vacuum main can be gained at any valve pit. However, some state codes still require cleanouts to be installed at specified intervals. In these cases and in stretches where valve pits are non-existent, access points should be constructed.

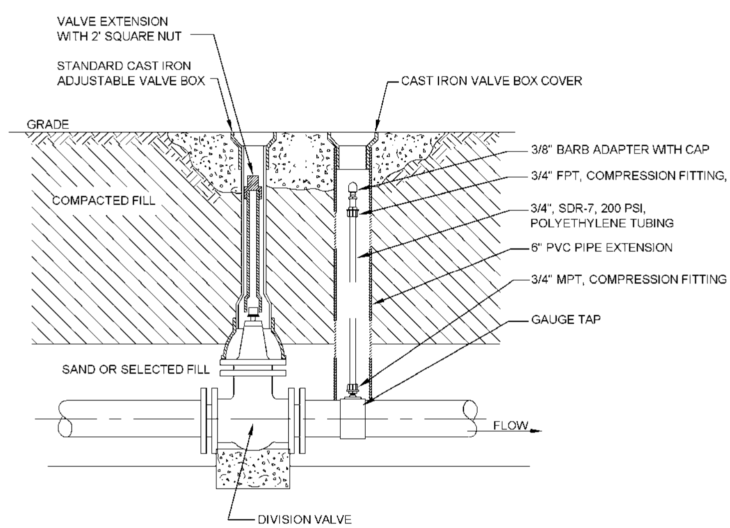


Figure 15
Division valve with gauge tap
(Courtesy AIRVAC)

### *F. Vacuum Station Design*

Section IIB, pages 4 & 5, described the purpose of the vacuum station and Figure 3 showed its major components. Additional information regarding the major station equipment follows.

**Discharge Pumps**

Duplicate pumps, each capable of delivering the design capacity at the specified head conditions should be used. These are typically horizontal, non-clog centrifugal pumps. Because the pump is drawing from a tank under vacuum, the NPSH calculations are especially critical. A certification from the pump manufacturer that the pumps are suitable for use in a vacuum sewerage installation is strongly recommended.

The sewage pumps are the most susceptible component to submergence so it would be wise to consider dry-pit submersible pumps for flood prone areas. These pumps may operate in a dry pit under normal conditions and if necessary continue to operate while submersed. The obvious disadvantage is a motor coupled to the pump casing that is sealed making maintenance more difficult. Submersible pumps tend to require slightly higher $NPSH_r$ than their non-submersible counterparts so some special arrangements may be necessary to satisfy this criterion as well.

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 (AIRVAC, 2005). 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. Clear PVC pipe is recommended for use as small air leaks and blockages will be clearly visible to the system operator. On small discharge pumps (generally less than 100 gpm), the equalizing lines should be fitted with motorized full port valves that close when the pumps are in operation.

To size the discharge pumps, use the following formula:

$$Q_{dp} = Q_{max} = Q_a \text{ x Peak Factor}$$

(Typical peak factors range from 3.0 to 4.0)

Where: $Q_{dp}$ = Discharge pump capacity (gpm)
$Q_{max}$ = Peak Flow (gpm)
$Q_a$ = Average flow (gpm)

TDH is calculated using standard procedures for force mains. However, head attributed to overcoming the vacuum in the collection tank ($H_v$) must also be considered, resulting in the following formula:

$$TDH = H_s + H_f + H_v$$

Where: TDH = Total Dynamic Head (ft)
$H_s$ = Static head (ft)
$H_f$ = Friction head (ft)
$H_v$ = Vacuum head (ft)

The $H_v$ value is usually 23 ft, which is roughly equivalent to 20 in. Hg (typical upper operating value). Since $H_v$ will vary depending on the tank vacuum level (16-20 in Hg, with possible operation at much lower and higher levels during problem periods), it is prudent to avoid a pump with a flat capacity/head curve.

Where possible, horizontal sewage pumps should be used, as they have less suction losses compared to vertical pumps. To reduce suction line friction losses, the pump suction line should be 2-in. larger than the discharge line.

Net positive suction head (NPSH) calculations are important in the discharge pump selection process. Nomenclature and typical values are given in Table 6.

Figure 16 is a diagram for calculation of $NPSH_a$ in a vacuum system. To calculate $NPSH_a$, use the following formulas:

$$NPSH_a = h_{avt} + h_s - h_f - h_{vpa}$$
$$h_{avt} = h_a - V_{max}$$

$NPSH_a$ must be greater than $NPSH_r$. $NPSH_a$ and TDH should be calculated for both the high and low vacuum operating levels and compared to the $NPSH_r$ at the corresponding point on the head/capacity curve.

## Table 6

Discharge Pump NPSH Calculation Nomenclature

| Term | Definition | Typical Value |
|---|---|---|
| $NPSH_a$ | Net positive suction head available, ft | (calculated) |
| $h_a$ | Head available due to atmospheric pressure, ft | 33.9 @ sea level<br>33.2 @ 500 ft<br>32.8 @ 1,000<br>29.4 @ 4,000 |
| $h_{avt}$ | Head available due to atmospheric pressure at liquid level less vacuum in collection tank, ft | (calculated) |
| $V_{max}$ | Maximum collection tank vacuum, ft | 18.1 @ 16-inHg<br>22.6 @ 20-inHg |
| $h_s$ | Depth of wastewater above pump centerline, ft | 1.0 (min) |
| $h_{vpa}$ | Absolute vapor pressure of wastewater at its pumping temperature, ft | 0.8 |
| $h_f$ | Friction loss in suction pipes, ft | 2.0 (ver. Pump)<br>1.0 (hor. Pump) |
| $NPSH_r$ | Net positive suction head required by the pump selected, ft | Varies by pump |

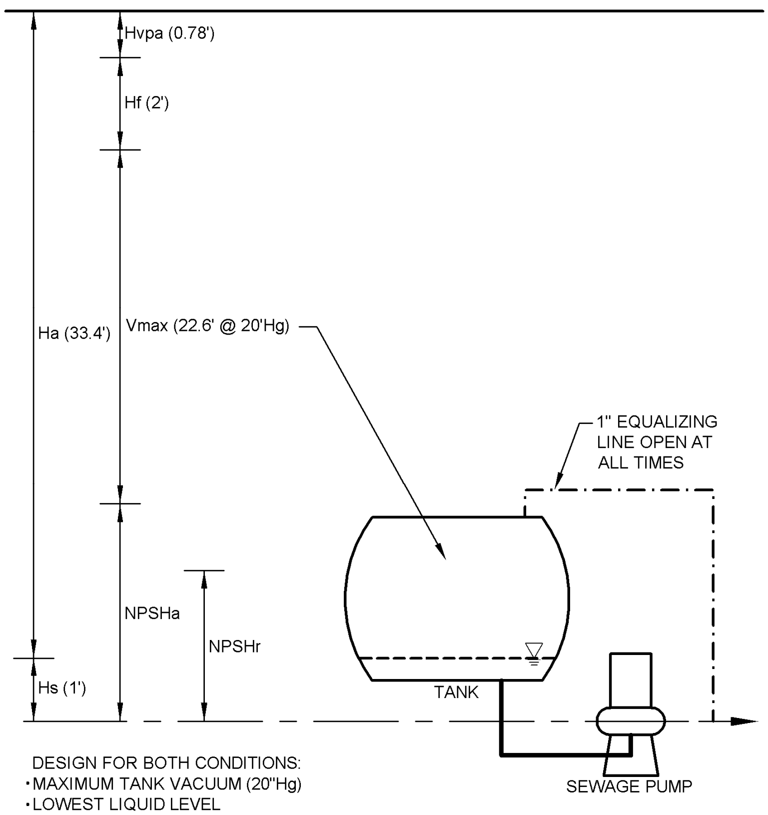


Figure 16
NPSHa calculation diagram with typical values
(Courtesy AIRVAC)

**Collection Tank**

Carbon steel, stainless steel and fiberglass tanks are acceptable. Carbon steel and stainless steel tanks should be of a welded construction and fabricated from not less than 1/4- in. thick steel plates. The tanks should be designed for a working pressure of 20-in. Hg vacuum and tested to 28-in. Hg vacuum. Fiberglass tanks may be substituted using the same specifications. Fiberglass tanks are to have 150 psi rated flanges.

Carbon steel tanks should be sand-blasted and painted. The internal coating usually consists of two coats of epoxy primer suitable for immersion in sewage. The external coating is one coat of epoxy primer and one coat of epoxy finish.

The tank should be furnished with the required number and size of openings, man-ways, and taps, as shown on the plans. In addition, the tank should be supplied complete with sight glass and its associated valves.

It is recommended that only one vessel be used for most projects. Should the single tank concept result in a tank too large to transport, dual tanks are recommended but this is very rare. Although a total tank failure would result in total system outage, no such failures have ever been reported.

Collection tanks are sized on peak flow to the vacuum station and to insure adequate operating volume to prevent sewage pump short cycles and emergency storage volume. Using these criteria, the sewage pumps will not operate more than 4 times per hour at minimum flow periods (2 starts per pump), nor start more than 7 times per hour at average flow (3.5 starts per pump) (AIRVAC, 2005). This is represented by the following formulas:

$$Vo = 15Q\min(Qdp - Q\min) \div Qdp$$

Where $Vo$ = Operating Volume (gal)

$Q_a$ = Average daily flow (gpm) = $Q_{min}/2$

$Q\min$ = Minimum Flow (gpm)

$Qdp$ = Sewage Pump capacity (gpm)

To the operating volume a safety factor of 3.0 is applied for emergency storage. An additional 400 gallons is added to this subtotal as a reserve volume within the tank for moisture separation and vacuum pump reserve volume.

$$Vct = 3Vo + 400$$

Where $Vct$ = Collection Tank Size (gal)

The minimum recommended size is 1000 gal. After sizing the operating volume, the designer should check to ensure an excessive number of pump starts per hour will not occur. This check should be performed for a sewage inflow equal to one-half the pump capacity.

When designing the collection tank, the sewage pump suction lines should be placed at the lowest point on the tank and as far away as possible from the main line inlets. The main line inlet elbows inside the tank should be turned at an angle away from the pump suction openings.

## Vacuum Pumps

Vacuum pumps may be either the sliding-vane or the liquid-ring type. In either case, the pumps should have a minimum (ultimate) vacuum of 29.3-in. Hg at sea level. Even though the pumps operate on short cycles, they should be capable of continuous operation.

Lubrication should be provided by an integral, fully re-circulating oil supply. The oil separation system should also be integral. The entire pump, motor, and exhaust should be factory assembled and tested with the unit mounted on vibration isolators, and should not require special mounting or foundation considerations.

To size the vacuum pumps, the following empirical formula has been used successfully (AIRVAC, 2005):

$$Q_{vp} = A \times Q_{max}/7.5 \text{ gal/ft}^3$$

Where: $Q_{vp}$ = Vacuum pump capacity (cfm)
$Q_{max}$ = Peak Flow (gpm)

"A" varies empirically with mainline length as shown in Table 7. The minimum recommended vacuum pump size is 150 cfm.

**Table 7**

"A" Factor for Use in Vacuum Pump Sizing

| Longest Line Length (ft) | "A" factor |
|---|---|
| 0 - 5,000 | 6 |
| 5,001 - 7,000 | 7 |
| 7,001 -10,000 | 8 |
| 10,000 -12,000 | 9 |
| >12,000 | 11 |

After the initial vacuum pump sizing is completed, a second calculation is made to ensure that the vacuum pump capacity is large enough for the connected pipe volume. This calculation will show the amount of time it will take the selected vacuum pumps to evacuate (pump-down) the collection piping from 16-20-in. Hg, assuming an operating range of 16-20-in. Hg. AIRVAC's 2005 Design Manual contains the formula needed to make this calculation.

Some systems require only 2 vacuum pumps. In this case, redundancy is required, with each pump capable of providing 100 percent of the design capacity. In larger systems, where 3, 4 or even 5 vacuum pumps are required, design capacity must be met with one pump out of service. For example, if a design capacity of 900 cfm is required, 4-300 cfm pumps are used (3-duty pumps @ 300 cfm/ea and 1 @ 300 cfm standby).

## Emergency (standby) Generator

The standby generator should be capable of providing 100 percent of standby power required for the station operation. It typically is located inside the station, although generators located outside the station in an enclosure are also acceptable.

In some cases a municipal utilities have designed for a pig-tail connection on the outside of the vacuum station to allow for the connection of mobile emergency generator hookup. This design allows the utility to have some flexibility and mobility with its emergency generators where the logistical distance between the utility's various pump/vacuum stations make this concept feasible,

## Station Piping

Wastewater, vacuum, and drain lines 4-in. and larger should be ductile iron, using AWWA/ANSI C110/A21.10 as standard. Pipe and fittings within the vacuum station should be flanged with EPDM gaskets. Exposed vacuum lines and other piping smaller than 4-in. can be Sch 80 PVC, 304 Stainless Steel, galvanized or Sch 40 black iron. Building sanitary drains may be constructed of Sch 40 PVC with DWV fittings.

The piping should be adequately supported to prevent sagging and vibration. It also should be installed in a manner to permit expansion, venting, and drainage. For fiberglass tanks, all piping must be supported so that the tank flanges support no weight. Flange bolts should only be tightened to the manufacturer's recommendations. Provisions must be allowed for inaccurate opening alignment.

All shut-off valves fitted within the collection station should be flanges, resilient coated plug valves with circular ports. Check valves fitted to the vacuum piping are to be of the 125 lb bolted bonnet, rubber flapper, and horizontal swing variety.  Check valves are to be fitted with Buna-N soft seats. Check valves fitted to the sewage discharge piping are to be supplied with an external lever and weight to ensure positive closing.  They should be fitted with soft rubber seats.

On the upstream side of each side of each vacuum sewer isolation valve, a vacuum gauge of not less than 4.5-in. diameter should be installed.  Gauges should be positioned so that they are easily viewed when the isolation valves are operated.  Diaphragm seals should not be used with compound gauges.

## Electrical Controls

Rather than using a Motor Control Center (MCC), most vacuum stations use a smaller control panel that is attached directly to the equipment skid.  These control panels are specifically designed for each station.

The control panel enclosure is to be NEMA Type 12 and is generally mounted on the equipment skid.  A main disconnect switch, sized to handle the current draw for all related vacuum station equipment is to be provided.

The panel includes motor starters for each motor.  Either IEC type or NEMA rated motor starters are used.  To reduce in-rush current, "soft-starts" or Variable Frequency Drives (VFD's) can be used.  The control panel also incorporates control relays or programmable logic controls, which then are connected to the various functions of the control panel system design.

Discharge pump level control relays are mounted inside the panel.  Conductance type level control rods are mounted through the tank wall and set to specific heights to maintain sewage pump operation and to provide alarm functions.

The panel should include pilot lights and hand-off-auto (HOA) switches. Hour-run meters are included for the operator to track daily run times of the vacuum and discharge pumps.

To monitor system performance, a 7-day chart recorder is installed in the enclosure.  The control panel should include a telephone alarm dialer, which monitors (3) three alarm functions:  low vacuum levels, high sewage conditions and power outages.

In small, simple vacuum station designs, the vacuum station skid manufacturer wires the control panel to each motor and control device.  Larger, more complex designs require the contractor to wire the control panel to the related junction boxes provided on the equipment.

Control panels can use either relay-logic or PLC logic.  Some prefer the simplicity of relay-logic and may not want the sophistication of using a PLC.  Others wish to have more control over the system by changing the ladder logic through laptop computers. Many of the larger municipalities prefer this type of logic as it matches other controls they may have with lift stations and treatment plants. Most recent systems use PLC logic.

In larger vacuum stations, the controls are typically house in a Motor Control Center (MCC). The Motor Control Center (MCC) is to be manufactured, assembled, wired, and tested by the factory in accordance with the latest issue of NEMA Publication ISC2-322, for Industrial Controls and Systems. The vertical section and the individual units shall bear a UL label, where applicable, as evidence of compliance with UL Standard 845. Wiring inside the MCC is to be NEMA Class II, Type B. Where Type B wiring is indicated, the terminal blocks should be located in each section of the MCC.

The enclosure should be NEMA Type 12-with-Gasketed Doors. Vertical sections shall be constructed with steel divider side sheet assemblies formed or otherwise fabricated to eliminate open framework between adjacent sections or full-length bolted-on side sheet assemblies at ends of the MCC.

The MCC should be assembled in such a manner that it is not necessary to have rear accessibility to remove any internal devices or components. All future spaces and wire-ways are to be covered by blank doors.

## Level Controls

Seven (7) probes inside the collection tank control the discharge pumps and alarms. These probes are 6-mm (1/4 in) stainless steel with a PVC coating. The seven positions are as follows:

1. Ground probe
2. Both discharge pumps stop
3. Lead discharge pump start
4. Lag discharge pump start
5. High level alarm
6. Reset for probe #7
7. High level cut-off: stops all discharge pumps (auto position only) and vacuum pumps (auto and manual positions)

Figure 17 gives approximate elevations of these probes in the collection tank relative to the discharge pumps and incoming vacuum mains.

An acceptable alternative to the seven probes is a single capacitance-inductive type probe capable of monitoring all seven set points. This type of probe requires a transmitter/transducer to send a 4-20 mA signal to the MCC.

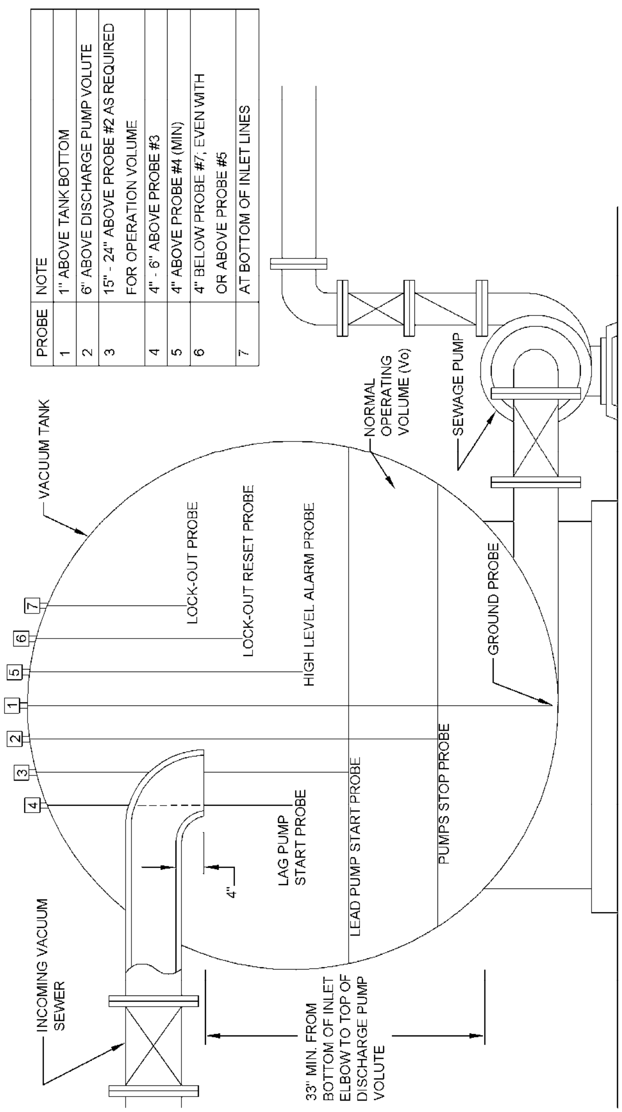


Figure 17
Typical Elevations of level control probes
(Courtesy AIRVAC)

**Monitoring system**

The fault monitoring system is used to alert the operator of any irregularities, such as a low vacuum level. 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.

If a voice communication-type automatic telephone dialing alarm system is used, it should be mounted on a wall adjacent to the MCC. If the monitoring system is to be housed within the MCC, provisions must be made to isolate the system from interference. The system should be self-contained and capable of automatically monitoring up to four independent alarm conditions. The monitoring system should be provided with continuously charged batteries for standby operation in the event of a power outage.

**Vacuum Gauges**

All vacuum gauges should be specified to have a stainless steel bourdon tube and socket and to be provided with ½-in. bottom outlets. Polypropylene or stainless steel ball valves should be used as gauge cocks. The connection from the incoming main lines to the vacuum gauges should be made of PVC or CPVC pipe. Copper pipe is not to be used for this purpose.

Vacuum gauges should be provided on the collection tank in a position that is easily viewed from the stairway leading to the basement. In addition, vacuum gauges should be provided on each incoming main line to the collection tank, immediately upstream of the isolation valve. These gauges should be in a position above the incoming main lines that is easily viewed from the operating position of the isolation valves.

**Vacuum Chart Recorder**

The vacuum station control panel should contain a 7-day circular chart recorder with a minimum chart diameter of 12- in. The recording range is to be 0-30-in. Hg vacuum, with the 0 position at the center of the chart. The chart recorder is to have stainless steel bellows.

**Sump Valve**

The basement of the vacuum station should be provided with a 15 in x 15 in x 12 in deep sump to collect wash-down water. A vacuum valve that is connected by piping to the collection tank empties this sump. A check valve and eccentric plug valve should be fitted between the sump valve and the collection tank.

**Odor control**

Odor control for vacuum systems is normally associated with airborne $H_2S$ within the vacuum pump exhaust. Various methods have been employed to successfully eliminate $H_2S$. The use of a bio-mass compost bed designed in accordance with EPA Manual *Odor and Corrosion in Sanitary Sewerage Systems*[2] have been used for many years in various locals in the U.S. and in foreign countries and is recommended assuming space is available at the site.

The designer is cautioned that the thermophylic bacteria of the bio-mass is not viable at high temperatures (>120° F) and the impact thereon from the heat of discharge to the bio mass should be considered. Thermophylic bacteria are susceptible to destruction at high heat and the odor control system should address either heat dissipation or reduction.

Additional methods employed include chemical neutralization, activated carbon absorption systems and absorption by manufactured bio-mass filters.

**Noise and Heat considerations**

Noise generated by a vacuum station is typically associated with the vacuum pumps. If desired, soundproofing features can be added to the vacuum station. Of the 200+ vacuum stations in the U.S., only a few have utilized this added protection.

The vacuum station generates heat primarily from the sewage pump motors and the vacuum pumps. Obviously this heat is added to ambient conditions and can add up during hottest periods of the day.

Vacuum stations are not normally air conditioned as long as adequate air exchange rates are provided through ventilation equipment to prevent excessive heat buildup. Allowing natural heat rising through roof-mounted vents with low air intakes is recommended. Maximum recommended operating temperature for station equipment is 104° (F).

In site locations where summertime temperatures typically reach into the high 90's, the design engineer needs to give consideration to the heating, venting and cooling requirements of the vacuum station. In these locations, experience has shown that interior temperatures of the vacuum station can easily exceed 100° F, possibly resulting in overheating of motor control panels.

# IV. CONSTRUCTION CONSIDERATIONS

Construction of a vacuum sewer system is similar to other *ACS* systems. Utilizing small diameter pipes in shallow trenches and having the ability to avoid underground obstacles virtually at will makes this type of construction attractive to contractors. There is, however, certain inherent construction issues associated with vacuum sewers.

It is imperative that those with a thorough knowledge of vacuum sewer technology perform inspection. The design of the system and its hydraulic limits must be understood by at least one member of the construction team.

## *A. Vacuum Main Construction*

The use of chain-type trenches is sometimes specified for service line installation where soil types allow, as they cause less disruption to the property owner's yard than does a backhoe. Rocky soils and some clayey soils that will not self clean from the trencher teeth may be impractical to excavate using a trencher, although special designs have been successfully employed for the former condition.

Many contractors use a backhoe for the service line excavation, since this same equipment is required for the excavation of the valve pit, which typically is located close to the main sewer. Many times this results in over-excavation of the service line trench. Over-excavation, coupled with the use of fittings that are typically required between the valve pit and main, can lead to future problems if proper bedding and backfill materials are not used.

Since the native material and intended contractor equipment is not always known, it is recommended that the contract documents specify surrounding the pipe with imported pipe zone backfill. If local materials meet the required specifications, they may be substituted at a reduced cost.

To minimize damage to the vacuum sewer main caused by subsequent excavation, route markers are sometimes placed adjacent to the main, warning excavators of its presence. Accurate as-constructed plans are helpful in identifying the pipeline location. A cable buried with the main can be induced with a tone so the main can be field located using common utility locating equipment. In other cases, a warning tape marked "vacuum sewer" is placed shallowly in the pipeline trench to further notify excavators.

## Line Changes

Unforeseen underground obstacles are a reality in sewer line construction. Water and gas lines, storm sewers, and culverts at unanticipated locations all may present difficulties during construction. Natural underground conditions, such as rock, water, or sand also may present more problems than anticipated.

With the straight line, constant grade requirements of gravity sewer construction, these obstacles often result in field changes. These field changes might include installing an additional manhole and/or removing and relaying part of the pipe at a different grade. The grade change could affect the depth and grade of the entire gravity sewer system. Another lift station may have to be installed. Alterations at the treatment plant could be required. The end result is an increase in contract price through change orders.

One key advantage of vacuum sewers is the flexibility they allow for line changes during construction. Unforeseen underground obstacles usually can be avoided simply by going under, over, or around them. There may be cases where line changes will be necessary, due to hydraulic limitations. However, the likelihood of this is greatly reduced when compared to conventional gravity sewers.

Line changes are made through the use of fittings. No 90-degree bends should be used in vertical or horizontal line changes (AIRVAC, 2005). Concrete thrust blocking generally is not necessary, however, compaction in the zone of abrupt change in direction is vital.

## Grade Control

The ability to make grade changes to avoid obstacles is an advantage inherent with vacuum sewers, but the abuse of this freedom can result in major problems. Grade changes should not be made without a thorough evaluation of how that change will affect overall system performance. This issue has been the cause of conflicts between the contractor and the engineer in past vacuum projects. The engineer's inspector instinctively desires to eliminate lifts to improve the system hydraulics, but this will result in a deeper installation. The contractor, on the other hand, desires to add lifts, which will result in a shallower installation. As long as neither party loses sight of the system's hydraulic limits and the effect on operational costs, a conflict does not have to take place.

Vacuum sewers must be laid with a positive slope toward the vacuum station. The only exception to this is where vertical profile changes (lifts) are made. The pipe must slope toward the vacuum station between lifts.

A minimum of 0.2 percent slope must be maintained at all times. To ensure this, a laser typically is required during construction. The use of automatic levels also is acceptable when handled by an experienced instrument operator. In areas where an obvious (>0.2%) downhill slope exists, the pipeline may follow the contour of the ground. The engineer's inspector should routinely check grade.

**Horizontal Directional Drilling (HDD)**

The use of directional drilling has increased greatly in recent years. While significant advancements in this technology have occurred, it has not yet developed to the point where it can be used on a wide scale basis for vacuum sewers. The major reason is the inability of the equipment to maintain such shallow (0.20%) slopes. At the time this manual went to publication, most HDD companies felt that the minimum attainable slope was around 0.50%. Designing with a minimum slope of 0.50% instead of 0.20% would result in either deeper vacuum mains or shorter line lengths before the static limit was reached. As a result, a decision to allow HDD must be made prior to the design process.

Sags and summits are not acceptable in vacuum systems as they can result in detrimental operating performance. For this reason, tolerances for directional drilling are the same as those required for open trenching. Those tolerances are typically 0.05'/100', or 0.05%. With a target slope of 0.20 %, this means the slope could vary from 0.15% to 0.25%.

The "minimum 50 ft at 0.20% prior to a lift" rule applies to directional drilling just as it does to open trenching. Contractors should not be permitted use the concept of adding lift(s) to make up any difference in elevation that may occur by completing a directional drill at something greater than 0.20%.

Table 8 shows general requirements when HDD is used in vacuum sewer construction.

| Table 8<br><br>Requirements for using<br>Horizontal Directional Drilling<br>To install vacuum sewers | |
|---|---|
| Item | Requirement |
| Slope | Installed pipe must meet slope tolerances (± 0.05' per 100 ft) |
| Sags (bellies) & summits | Are not acceptable |
| Quality control | HDD firm must be able to electronically verify installed slopes at the time of the installation |
| System integrity | Installed pipe must be capable of passing daily & final vacuum tests |
| Pipe materials | Must mate up to manufacturer's products and other system components |

On non-critical lines, it may be possible to actually design for slopes greater than 0.20% in areas where directional drilling is desired. This would not be a construction tolerance but rather a design decision that allows for a more attainable slope, such as 0.50%.

Incorrect slopes or sags and summits have larger negative affect when a vacuum main is involved rather than when a branch or service line is involved. An incorrect slope on a service line would affect the operation of just that particular service line, whereas an incorrect slope on a vacuum main would affect not only that main, but all connected branch and service lines as well.

**<u>Vacuum testing during construction</u>**

While a final vacuum test of the entire collection system ultimately will be performed to ensure the integrity of the collection system, it is recommended that daily testing also be done. Doing so will increase the likelihood of a successful final test, as the pipe layers will gain immediate feedback concerning their workmanship. Also, a leak is much easier to locate when only the section installed that day is examined rather than the entire system.

The duration of the daily vacuum test is 2 hours. The pipe laid that day should be plugged and subjected to a vacuum of 22 -n. of mercury, allowed to stabilize for 15 minutes. The allowable loss is limited to no more than 1% vacuum pressure per hour (approximately ½” of Hg). During the daily testing, all joints should be left exposed. If any section of the sewer fails the test, it should be reworked prior to laying new sections of sewer. Upon successfully passing the test, the day’s construction should be backfilled prior to shift completion (AIRVAC, 2005).

Where climatic changes may occur during a vacuum test, it is recommended that pipe temperature and atmospheric pressure be recorded at the beginning and end of the test, and the test results adjusted to correct for these changes.

### *B. Valve pit installation*

The relationship between the ground elevation where the pit setting will be situated and the elevation of the customer's building sewer dictates the depth of service required and the type of pit required. The length of connecting lateral required must be considered to allow for sufficient slope of the building sewer.

Prefabricated valve pits with fixed dimensions can sometimes make pit location critical. Moving the pit to a lower elevation, while allowing additional fall for the building sewer, may result in lift being necessary to connect to the main. Moving the pit to a higher elevation may result in insufficient fall available for the building sewer. Each valve pit location should be evaluated for adequacy and verified by the engineer to the contractor prior to shipment of the valve pits.

It is good practice to boldly field mark the location of the service lateral with properly identified lath or stakes a few days prior to installation. This serves as a reminder to the property owners about the intended location and may cause them to recognize some reason why the location should be changed. It also serves as a notice to neighbors if property lines are in doubt.

The orientation of the valve pit is a function of the number of house connections to the pit and the placement of the wye on the vacuum main. The 3-in. vacuum service lateral that exits the valve pit must always be at a 45-degree horizontal angle to any of 4-in. incoming gravity stub-out pipes (see Fig 18).

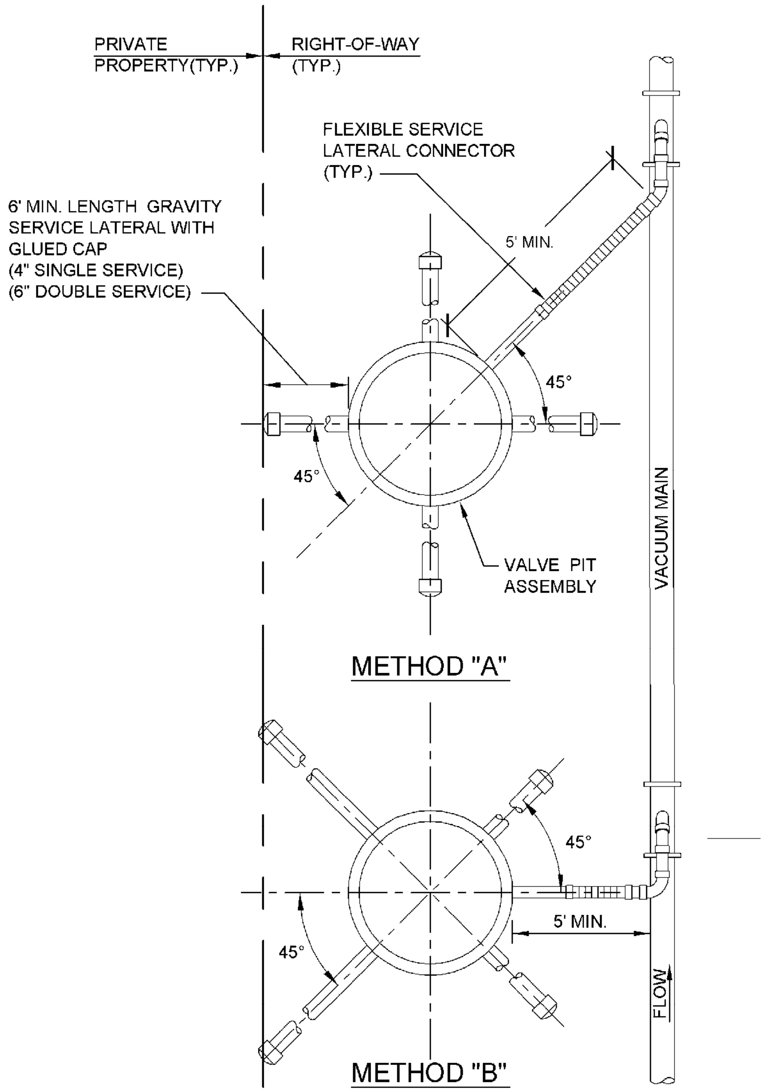


Figure 18
Typical configurations for gravity connections
(Courtesy AIRVAC)

**Pit installation**

The installation of the valve pit is divided into two (2) phases:  at the contractor's workshop and at the installation site.  The 2005 AIRVAC *Operation, Maintenance and Installation Manual*[3] provides detailed instruction for each of the following tasks.

**Table 9**

Valve Pit Installation Tasks

| Where | Task | Time (hrs) |
|---|---|---|
| Contractor's workshop | Cut the stub-out(s) to the required length | 0.15 |
| | Install O-ring on pit bottom & bolt pit bottom to sump | 0.35 |
| | Test sump (w/out holes) for tightness | 0.25 |
| | | 0.75 hrs |
| Installation Site | Excavate pit to appropriate depth | 0.75 |
| | Cut hole(s) in sump for stub-out(s) | 0.10 |
| | Lower sump/pit bottom into hole & install stub-outs | 0.20 |
| | Backfill and compact up to pit bottom | 0.15 |
| | Test sump (w/sub-outs) for tightness | 0.25 |
| | Align & lower valve pit onto pit bottom | 0.10 |
| | Install floatation collar, if required | 0.15 |
| | Install 3" flexible connector | 0.10 |
| | Install cast iron frame & cover | 0.10 |
| | Complete backfill | 0.35 |
| | | 2.25 hrs |

The times shown above are attainable with desirable subsurface conditions, but can extend all the way to a full day if the installation location has a high groundwater table that requires dewatering systems or where rock exists that requires specialized excavation.

**Connecting the pit to the main**

Contractors typically have a crew installing main lines and a second crew installing the on-lot services (e.g., valve pit settings). It is common for the line crew to install a wye fitting on the main to eventually accept the service lateral piping from the pit crew. Typically, the pit crew installs the pit setting and then connects the pit to the main. The remaining work, connecting two fixed points at varying inverts and locations, but requiring rigid connection piping, can result in the contractor using an excessive amount of fittings. Proper planning and coordination between line and pit crews can minimize the use of fittings in the service lateral.

To eliminate the potential problems caused by using rigid pipe and fittings to connect the valve pits to the main, AIRVAC developed a special product called the "flexible connector". The flexible connector uses a special 3-inch PVC flexible hose to give a degree a flexibility that allows for these difficult connections. Connections at both ends of the connector are the same as with PVC pipe. The use of a flexible service connector virtually eliminates stress-related leaks caused by poor workmanship or ground settlement.

Many times fittings are located within the pit excavation. This over-excavated zone is one where lack of compaction could easily lead to future settlement, which can lead to fitting failures.

**Sump tightness test**

It is important to test the sump portion of the valve pit for water tightness. The sumps are tested twice.

The first test is done at the contractor's workshop or at the construction site. This is done prior to any holes being cut into the sump. The purpose of this test is ensure the sump is not defective or has not been damaged during shipment.

The second test is done after the complete valve pit has been installed at the site. This second test is to assure that a tight seal has been achieved after the installation of the stub-out lines.

The 2005 AIRVAC *Operation, Maintenance and Installation Manual*[3] provides detailed instruction for the sump testing.

### *C. Vacuum Station Construction*

There is nothing unique about the construction of a vacuum station. Standard structural, mechanical, electrical and plumbing practices that are employed at other similar type structures (treatment plants, lift stations, etc.) are followed.

### *D. Final Vacuum Testing & System start-up*

Start-up is usually conducted in two phases: the vacuum station and the collection system. The manufacturer that supplies the vacuum station equipment generally conducts all of the tasks related to the vacuum station start-up. The Contractor, with the manufacturer's help, is normally responsible for the collection system start-up task.

**Vacuum Station start-up**

The supplying manufacturer's technician will perform the general startup tasks shown in Table 10. Detailed start-up procedures are contained in the manufacturers' O&M Manual.

**Table 10**

Vacuum Station start-up Tasks

| Start-up tasks | Description |
|---|---|
| Vacuum Pump test | Adjust operating vacuum range; set low vacuum alarm level; verify vacuum pump capacity |
| Sewage pump test | Verify motor rotation; verify pump capacity; check discharge pressure |
| Electrical review | Verify incoming voltages; verify voltage and amperage are correct for all motors; operate system under various scenarios to verify that all relays, sequencing and alarms are working properly |
| Level controls | Set level control probes for all control points |
| Final vacuum test | Isolate station from collection system and conduct final 4-hr. vacuum test |

After the collection system start-up is completed, the technician will return the station to its appropriate operational levels and then place the entire system in the automatic mode for commissioning into active service.

**<u>Collection System start-up</u>**

Once the vacuum station has been checked out successfully, the technician will move on to the collection system. The isolation valves between the collection tank in the station and the collection system incoming lines will be opened and the entire vacuum station and collection system will be placed under vacuum. Startup related to the vacuum mains consists of vacuum testing and line flushing.

The supplying manufacturer's technician will perform the general startup tasks shown in Table 11. Detailed start-up procedures are contained in the manufacturers' O&M Manual.

**Table 11**

Collection system start-up Tasks

| Start-up tasks | Description |
|---|---|
| Complete 4-hr final vacuum test | Isolate collection system from vacuum station and conduct final 4-hr vacuum tightness test |
| Flush system | After a successful vacuum test, introduce water into the collection system at the far extremities of the lines and other various points throughout the collection system to systematically flush any debris that may have entered the system during construction to the station. |

Following the successful completion of line flushing, the technician will return the station to its appropriate operational levels and then place the entire system in the automatic mode for commissioning into active service.

**Vacuum testing summary**
A summary of the various testing required is shown on Table 12.

**Table 12**

Vacuum Testing

| What | When | Test Duration | Beginning Test Level | Acceptable loss |
|---|---|---|---|---|
| Collection piping | Daily | 2 hrs | 22 in-Hg | ½ in-Hg |
| Collection piping | Final test | 4 hrs | 22 in-Hg | 1 in-Hg |
| Vacuum Station | Final test | 4 hrs | 22 in-Hg | 0 in-Hg |

### *E. Construction Inspection*

Primary inspection responsibility lies with the owner or their designated inspector, which usually is the design firm. To supplement this, the vacuum vendor may provide technical assistance in various ways ranging from full time direct technical services to training services. Not only can the vacuum vendor assist in ensuring proper installation, but they can also provide immediate resolutions to unforeseen construction difficulties as well as provide advice on whether lifts can be added or deleted. This helps minimize contractor downtime, which results in fewer change orders. Generally, the cost of adding a vacuum vendor Field Representative is less than 1-2% of the total project cost.

It is not uncommon for the Utility to require the supplying manufacture to assist the design engineer during the construction phase. This is due to the unique nature of the technology. In this case, the manufacturer's field representative will assist the inspector with the following tasks.

**Duties – Vacuum main installation**
The inspector is to confirm that lines are installed as planned. Grades, distances and elevations are spot-checked, with particular attention paid to vertical profile changes. The inspector should see that branch and service lateral installations and horizontal direction changes are in compliance with established standards.

A check is made of the type of pipe and fittings being used to insure that they suitable for vacuum service and that proper certifications are in contractor's possession. Trench conditions are observed to insure that adequate soil conditions exists, and that proper bedding and compaction are carried out in conjunction with the contract documents.

The inspector also will watch the daily testing of vacuum sewer mains to insure compliance with standards. Finally, the inspector must maintain a neat, legible and accurate set of as built drawings and field notes.

**Duties – Valve pit installation**

The inspector will observe sump testing to see that it is conducted in accordance with manufacturer's standards. He/she will also insure that all field cut penetrations are neatly cut, reasonably circular and are located in accordance with manufacturer's recommendations.

Other duties include the verification that the valve pit setting is placed in accordance with construction drawings, that the 3-in service lateral is properly aligned with the 3-in suction pipe, that the pit assembly is plumb and reasonably level and that the pit depth is in accordance with design limits.

Finally, the inspector must maintain a neat, legible and accurate set of as built drawings, field notes, and valve pit installation forms.

**Duties – Vacuum Station installation**

The inspector will observe the sub-soil conditions, site drainage, dewatering operations, the placement of concrete and steel reinforcement and the proper use of water stop between concrete joints. The alignment of all wall penetrations for vacuum mains and the force main will be checked and compared to the construction drawings and shop drawings. Routing of vacuum pump exhaust lines will be checked. The inspector will observe and supervise the final system test and station start up and provide documentation as required.

**Record drawings**

As is common with all system types, field changes will occur during construction. The changes should be reflected on the record drawings, which are commonly referred to as "as-built drawings". Certain information specific to vacuum systems are discussed below and should be included with the record drawings.

An index map showing the entire system should be included in the as-built drawings. Shown on this map will be all key components, line sizes, line identifications, valve pit numbering and locations, and division valve locations. Detailed plan sheets of each line of the collection system should be included, with dimensions necessary to allow the operator to locate the line as well as all related appurtenances.

Unique to a vacuum system is the need for an as-built hydraulic map. This is similar to an index map but includes special hydraulic information. This simple but vital information allows the operator to make intelligent decisions when troubleshooting the system.

Important information to include on the as-built hydraulic map is 1) the locations of every lift, 2) the amount of vacuum loss at key locations, such as the end of a line or the intersection of a main and branch line and 3) number of main branches, number of valves in each branch, and total footage (or volume) of pipe in each branch.

Another tool that is helpful to the operator is an as-built drawing of each valve pit setting. These drawings will show the location of the setting relative to some permanent markers (house, power pole, etc.), the orientation of the gravity stub-outs, the depth of the stub-outs, and any other pertinent site-specific information. The operator must update or supplement these records as new customers connect to the system.

### *F. Bidding Issues*

There is no one best means of procurement. Different bidding formats are necessary so that the best for a given situation can be selected (WEF, 1995). Some common bidding formats are:

- Conventional open bid
- Base/substitute bid
- Pre-selection of major equipment

The 1995 WEF document, *Engineered Equipment Procurement Options to Ensure Project Quality*[4] contains a very thorough discussion on each of the above procurement options. The reader is highly encouraged to review this manual and use the method that best suits the situation.

# References

1. AIRVAC 2005 Design Manual, Rochester, IN., 20045.

2. *Odor & Corrosion in Sanitary Sewer Systems* .EPA, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1991.

3. AIRVAC Operation, Installation & Maintenance Manual, Rochester, IN., 2005.

4. *Engineered Equipment Procurement Options to Ensure Project Quality*, Water Environment Federation, Alexandria, VA., 1995