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Vacuum Sewers

O&M and System Management Considerations

PDHengineer Course No. C-4029

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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. In addition to proper design, proper operation and maintenance (O&M) is of utmost importance for these systems to perform efficiently.

This course is Part III of a three part series on vacuum sewers and will focus on operation & maintenance and system management considerations for vacuum sewer systems. Part I discusses the basics of vacuum sewer technology by providing a broad overview of the technology while Part II focuses on the design and installation aspects related to vacuum sewers.

II. EVALUATION OF OPERATING SYSTEMS

A. Operating history of vacuum sewers

Early vacuum systems were often plagued with consistent operational problems. Small diameter vacuum mains, improperly planned vacuum main profiles, too large liquid slug volumes, and insufficient air all resulted in transport problems¹. Adding to the difficulties was the fact that they were installed without sufficient field experience, and with system components that were not yet fully reliable. In addition, operation and maintenance guidelines were not yet available. Frequent service calls and high power bills were common during this era.

Several breakthroughs occurred in the 1980's that led to significant improvements in the technology. These included the introduction of the saw-tooth profile, an improved valve controller, the use of gasketed pipe and the use of larger pipe and vacuum pumps. Many feel that more progress was made in the vacuum sewer industry during this decade than in other time. Service calls were less frequent, systems were more energy efficient, and overall the systems were becoming more reliable.

Improvements in the technology continued throughout the 1990's to the present day. A better understanding of vacuum sewer hydraulics, improved system components, and established operation and maintenance guidelines have combined to lead to significant operational improvements.

Today's vacuum systems are significantly different than the systems of the 1970's. Efficiency and reliability are the two areas where the most improvement has occurred. Continuing research and development is expected to further improve the technology.

B. O&M data: 2003 Operator Survey

In 2003, a survey form was sent to selected operators of vacuum systems. An attempt was made to survey systems that would give a good cross section of the technology. Age of the system, topography, geographical location and size were considered in the selection process. O&M data from 22 projects, with a total of 49 operating systems, was gathered (see Table 1). This represents about 20% of the operating systems in the U.S.

To be consistent with the O&M data previously reported in the 1991 EPA Manual, *Alternative Wastewater Collection Systems*², the survey requested information on labor, power and service call history.

For the labor component, operators were asked to breakout their maintenance effort into 3 categories: routine (day-to-day), preventive (planned/scheduled) and emergency (service calls). Adjustment to the raw data was required in some cases as several operators reported preventive maintenance as routine maintenance or vice-versa. The data was reduced to the ranges and averages shown in Tables 2 thru 5.

Table 1

2003 Operator Survey

Project	# connections	# vacuum stations	# vacuum valves	House to Pit ratio	Yr operational
Plainville, IN	270	1	163	1.66	1975
Westmoreland, TN	1000	4	550	1.82	1979
Fairmount, MD	238	1	159	1.50	1981
Queen Anne's Co, MD	6250	14	2299	2.72	1981
White House, TN	1177	2	575	2.05	1987
Alton, KY	430	4	210	2.05	1987
Theresa, NY	237	1	141	1.68	1989
Beallsville, PA	235	1	127	1.85	1991
Silver Lake, IN	492	2	192	2.56	1992
Waverly, WV	140	1	114	1.22	1992
Montpelier, OH	300	1	120	2.30	1993
Crystal Lake, OH	975	2	438	2.23	1994
Pine Grove, WV	380	1	184	2.07	1994
York County, VA	2238	5	1049	2.13	1995
Glen Park, NY	166	1	110	1.51	1995
Wolcottville, IN	725	2	390	1.86	1996
Crisfield, MD	258	1	162	1.59	1997
Kotlik, AK	102	1	75	1.36	1998
Jimmersontown, NY	200	1	98	2.04	1999
Iron Mountain Lake, MO	368	1	241	1.53	2000
Stanfield, NC	190	1	129	1.47	2001
Forest, OH	146	1	65	2.25	2002

Labor

The Operator Survey showed that labor associated with the vacuum station was relatively minor and predictable. Most viewed the labor effort for a vacuum station as similar to that required for a lift station in a conventional system (see Table 2).

Table 2			
Labor: Vacuum Station (from 2003 Operator Survey)			
	Range reported (hrs/yr/station)		Average (hrs/yr/station)
Category	Low	High	Average
Routine	100	600	250
Preventive	0	90	50
Emergency	0	85	30

Labor associated with the vacuum mains varied widely, as this was generally was a function of whether any major line problems occurred in the past year. While the upper values shown on Table 3 did occur, the vast majority of operators reported few, if any problems with the vacuum mains. The average values are a more realistic view of a normally operating system.

Table 3			
Labor: Vacuum Mains (from 2003 Operator Survey)			
	Range reported (hrs/yr/system)		Average (hrs/yr/system)
Category	Low	High	Average
Routine	0	100	30
Preventive	0	100	20
Emergency	0	110	10

For the labor associated with the vacuum valves, some operators reported preventive maintenance as routine and vice-versa. Others reported no preventive maintenance at all. The raw data was reduced and the resulting ranges and averages shown in Table 4.

Table 4			
Labor: Vacuum Valves (from 2003 Operator Survey)			
	Range reported (hrs/yr/valve)		Average (hrs/yr/valve)
Category	Low	High	Average
Routine	0.20	0.90	0.50
Preventive	0.00	1.00	0.40
Emergency	0.10	1.35	0.60

Power

In most cases, the operators reported their power consumption in dollars (year 2003). Very few reported the unit charge for electricity (\$/KwHr). An average cost of \$0.07/KwHr was assumed, and the power costs were converted to the power consumption figures shown in Table 5. Because of the large disparity in power consumption between older and more recent systems, the data was broken into 2 eras.

Table 5			
Power Consumption (from 2003 Operator Survey)			
	Range reported (KwHr/yr/conn)		Average (KwHr/yr/conn)
Category	Low	High	Average
Pre- 1990 systems	430	570	500
Post-1990 systems	200	400	300

C. Mean Time Between Service Calls (MTBSC)

MTBSC is calculated by dividing the number of valves by the number of service calls over a 1-year period. For example, a system with 500 valves that required 50 service calls in a year would have a MTBSC of 10 years.

An EPA *Technology Transfer Seminar Publication*, prepared in 1977, detailed the failure rate (MTBSC) of some of the early vacuum systems. In general, the MTBSC of the early systems ranged from less than 1 year to more than 8 years; all but one of the systems had a MTBSC of less than 4 years (EPA, 1977). In the 1991 EPA Manual, *Alternative Wastewater Collection Systems*, the MTBSC of the 6 systems visited ranged from 1 year to 22.5 years (EPA, 1991), with an average MTBSC of 2.2 years.

The 2003 Operator Survey showed a range of MTBSC of 2 to 27 years, with the average being 5.1 years. This survey included many of the early systems that have lower MTBSC values. Even with these included, the overall MTBSC figure has increased over the years.

Era	Source	MTBSC
6 systems (1970-1989)	1991 EPA Manual	2.2 yrs
49 systems (1970 - 2003)	2003 Operator Survey	5.1 yrs

D. Historical problems

Each of the systems visited as part of the 1991 EPA Manual effort experienced some type of problem that predominated as a demand on O&M staff time. However, most were short lived. The results of the 2003 operator survey indicate that many of these early problems have vanished (see Table 7).

Table 7		
Summary of Historical Problems		
	Pre - 1990 systems	Post -1990 systems
	As reported in the 1991 EPA Manual	Per the 2003 Operator Survey
Component defect Broken controller spring Unreliable controller Shaft/seal Plug valve	Isolated cases Until the mid 80's Until the mid 80's Isolated cases	No longer a problem No longer a problem No longer a problem No longer a problem
Design shortcomings Pump cavitations Leaking check valves Oversized vacuum pumps	Isolated cases Until mid 80's Mid 80's	Not as frequent, but still a concern No longer a problem No longer a problem
Operator Error WW into vacuum pumps	Fairly common	More safeguards now, but still a concern
Construction related Line breaks Broken fittings Construction debris Heat in station Broken cleanout	Common w/solvent weld Common w/solvent weld Common after startup Isolated cases Fairly common	Rarely w/gasketed pipe Rarely Not as common due to operator training Still a concern when VFD's are used Less frequent w/fewer cleanouts
Equipment malfunction Faulty level control Faulty telephone dialer	Isolated cases Isolated cases	Rarely; improved technology Rarely; Improved technology
Extraneous water System waterlogging Water in controller I&I	More likely before saw-tooth # 1 component problem Root cause of most problems	Less likely now, but still a concern Less frequent, but still a concern Still the root cause of most problems

As is the case with other system types, extraneous water (I/I) is the root cause of most problems, whether it is heat build-up in the station due to excessive pump run-times or problems with the valve controller due to excessive cycles. In a vacuum sewer system, the only potential source of I/I is the homeowner's building sewer, where even a small amount of I/I can have a detrimental effect. Accepting flow from an existing gravity system, where I/I is common, further exaggerates the problems. (see box below).

The number one component-related problem remains "water in the controller", however, the incidence rate of this happening has drastically fallen over time, as is evidenced by the increasing MTBSC values of the recent systems. Water in the controller is a by-product of system problems that occur as a direct result of extraneous water (I/I) that is allowed to enter the system.

SITUATION TO AVOID!
ACCEPTING FLOW FROM AN EXISTING GRAVITY SYSTEM

Of all of the potentially bad situations that can occur, perhaps none is more damaging to a vacuum system than excessive flow that enters a vacuum system via an existing gravity system. Problems ranging from sluggish, inefficient flow transport to temporary system failure have resulted. With new construction, one can fairly accurately predict average and peak flow and design the vacuum mains and vacuum station accordingly. By accepting flows from an existing system, another element is introduced into the equation: infiltration & inflow (I/I).

Should it be possible to accurately predict I&I, this situation can be considered, but still with caution. An analysis of the existing gravity system must be done. This would include having flow records that identify the magnitude of flow that can be expected during normal periods as well as rain events (minimum 1 year of flow data). Even then, should there be a large difference between normal daily flow and flow during a rain event, it is recommended that the existing gravity flow be handled by other means.

(AIRVAC, 2005)

III. OPERATION & MAINTENANCE CONSIDERATIONS

A. *Staffing Requirements*

Because they are mechanized, vacuum systems have a reputation as being O&M intensive. This may have been true of the early vacuum systems; however, information from system operators suggests that the effort to operate and maintain a modern vacuum system is typically overstated.

One key to a successfully operating system is the attitude, training and skill of the system operator. An even more important consideration may be how the maintenance staff is structured and organized. Maintenance staffs that divide operating responsibility by system components, e.g., one division responsible for the vacuum station, another responsible for the vacuum mains and a third responsible for the valves are rarely successful. Successful operations are those that have at least one operator who is responsible for the entire system (*see box below*).

KEY TO SUCCESSFUL OPERATION THE SYSTEM APPROACH

The major components of a vacuum system...the interface valves, the piping network, and the vacuum station... are interrelated and must be designed to work as a **system**. Even more importantly, they must be operated as a system, not as individual components.

Making a change at the vacuum station affects not only the station components, but also the hydraulics of the vacuum mains and the operation of the valves. Cause and effect can only be learned by understanding how the entire system works and not by concentrating solely on one particular component.

For this reason, the most successful systems are those that are operated by a group with a single thought process. There is nothing wrong with several operators working together as long as they all know how the **system** responds to their actions.

B Operator Training

It is desirable for the management entity to hire the system operator before or during the period when the system is under construction. This allows the operator to become familiar with the system, including the locations of all lines, valve pits, division valves, and other key components. Also, the operator may assist the construction inspector as a means of becoming more familiar with the system.

Further training may be offered by manufacturers at their facilities and management should take advantage of it. By viewing a small-scale vacuum system that includes clear PVC pipe with various lift arrangements, trainees can watch the flow inside a clear pipe during a wide variety of vacuum and lift conditions. Faults can be simulated so that the trainee can gain troubleshooting experience. Manufacturers also provide schooling where the operator is taught valve operation and overhaul and vacuum station maintenance.

The best training is actual operating experience. As sometime happens, the best knowledge is often gained from operating mistakes. This is especially true at startup time. During this time, the engineer, who provided day-to-day inspection services during construction, is gradually spending less time on the system. The operator is busy setting vacuum valves and inspecting customer hookups. Complicating the situation is the fact that the operating characteristics of the system continually change until all of the customers are connected and all of the valves are fine-tuned. However, with the operator(s) being preoccupied with other tasks, this fine-tuning sometimes is not done and problems develop. The biggest concern during this period is that community confidence in the vacuum system not be lost.

This training gap is present at the startup of virtually every vacuum system. One solution is for the engineer to budget a 3 to 6 month on-site training service during the start-up period to aid the system operator in the fine tuning and troubleshooting any early problems. The operator will benefit from the engineer's systematic approach to problem solving. This most likely will instill a certain degree of confidence in the operator(s) concerning the system. Operator attitude is vital to the efficient operation of a vacuum, or any mechanically based, system.

C. Maintenance

There are two major classifications of maintenance: normal and preventive maintenance and emergency repairs or maintenance. A well-conceived asset management program emphasizes the former and minimizes the latter.

Normal & Preventive Maintenance

Vacuum systems operate and must be maintained 365 days a year. Variations in operation and maintenance workloads occur, making it imperative that preventive maintenance be planned and scheduled. This will ensure that there is no idle time during non- peak workload periods. Inspection and maintenance planning and scheduling involves time, personnel, equipment, costs, work orders, and priorities.

A preventive maintenance schedule for all major equipment should be developed. To initiate the preventive maintenance tasks, a work order system should be established. This system identifies the required work, priority of task, and any special information, such as the tools or parts required for the job.

Vacuum Station

A properly designed vacuum station will be equipped with a fault monitoring system, such as a telephone dialer or a telemetry system. These systems monitor the operation of both the vacuum station and the collection system, and automatically notify the operator of low vacuum, high levels of sewage in the collection tank, and power outages.

Normal operation includes visiting each vacuum station daily. Some daily maintenance procedures include the recording of pump running hours and oil and block temperature checks. Once an operator is familiar with the operating characteristics of the system, a simple visual check of the gauges and the charts in the station will provide an adequate alert of any problems. This visual check along with recording operating data generally takes about 30 minutes.

Daily, weekly, monthly and semi-annual tasks associated with the vacuum station are shown on Table 8.

Preventive maintenance for the major equipment at the vacuum station should be done in accordance with manufacturers' recommendations. In addition to the items in Table 8, yearly (annual) maintenance might include removal from service and comprehensive inspection of check valves, plug valves, vacuum pumps, sewage pumps, generator, and the telephone dialer.

Collection system piping

On a normal day, the operator will not be required to visit the collection system. Normal station gage and chart readings are an indication that the collection system is fine.

Scheduled maintenance on the collection piping should be minimal. Areas where difficult or unusual conditions were encountered during construction should be visited periodically.

At least once a year, the division valves should be checked. This is done by moving the valve through the entire opening and closing cycle at least once. This procedure is known as “exercising” and will keep valves in good operating condition. In addition, it will familiarize any new operating personnel with the location of all these valves.

Vacuum Valve

Depending on a system's history of emergency valve breakdown maintenance, some periodic inspection may be required. As with pressure sewer systems, certain on-lot units are prone to more problems than the rest of the system.

Access to valves for maintenance reasons is gained by removing the manhole cover on the valve pit. Routine maintenance is easily performed inside the standard valve pit from the ground surface. The only tools required are a manhole cover pick and a sensor pipe puller to drain any ground water that may have accumulated in the valve pit.

All vacuum valves should be inspected at least once each year³. They should be manually cycled to see that they are operating properly. The controller timing cycle should be recorded and compared to the original setting. If necessary, the timing should be reset and recorded. The operator should check for dirt or water in the controller, valve or tubing. If used, the above ground vent screens should be checked to see that that are clear of debris, spider webs, etc.

Table 8 summarizes the normal daily, weekly and monthly tasks for the system.

Table 8	
Normal Vacuum System O&M Tasks And Frequencies	
Frequency	Task
Daily	Visually check gauges/charts Record all pump run times Check oil level in vacuum pump sight glass Test cycle the AIRVAC sump valve in station
Weekly	Test cycle the AIRVAC sump valve in station Change chart on chart recorder Exercise generator
Monthly	Change oil and oil filters on vacuum pumps Remove and clean inlet filters on vacuum pumps Test all alarm systems Check all motor couplings and adjust if needed Clean all sight glasses Exercise all shut off valves (vacuum station)
Semi-annually	Exercise isolations valves (vacuum mains) Conduct external leak test on all vacuum valves Check valve timing and adjust if needed

Every 5 years, each controller should be removed and re-built³. For valves that cycle more frequently, the controller should be rebuilt every three (3) years or 500,000 cycles. These would typically be valves installed in buffer tanks or other high-use locations. The controller should be replaced with a spare and the removed unit returned to the owner's workshop. Rebuilding typically involves replacing the shaft seals, greasing the shaft, and cleaning all components.

Every 10 years, each vacuum valve should be removed, a spare put in its place, and the old valve returned to the workshop³. The valve should be taken apart and inspected for wear. If worn, the valve seat should be replaced and a new shaft seal and bearing should be fitted during reassembly.

Table 9 summarizes the preventive maintenance tasks and their frequencies.

Table 9	
Other Preventive Maintenance Tasks And Frequencies	
Frequency	Task
Every Year	Exercise Division valves (station & vacuum mains) Inspect Vacuum and sewage pumps for wear Visual inspection of all valve pits and valves Check valve timing and adjust if needed
Every 3 years	Rebuild Controller (buffer tank valves only)
Every 5 years	Rebuild Controller (most valves)
Every 10 years	Rebuild valve

Normally the operator will remove a valve or controller and replace it with a spare. The removal and replacement procedure takes about 5 to 10 minutes. The valve or controller is then taken to the maintenance show where rebuilding takes place. The time required to rebuild controllers and valves is shown on Table 10.

Table 10			
Time Requirements for Rebuild Tasks			
Item	Maintenance Interval	Personnel Required	Labor (hours)
<u>Physical Inspection</u>	Every year	1 man	0.50 hrs
<u>Controller Rebuild</u>	Every 5 yrs	1 man	0.25 hrs
Sanitize			0.50 hrs
Rebuild			<u>0.25 hrs</u>
QC tests			1.00 hrs
<u>Valve Rebuild</u>	Every 10 yrs	1 man	0.25 hrs
Sanitize			0.25 hrs
Inspect			1.00 hrs
Rebuild			<u>0.25 hrs</u>
QC tests			1.75 hrs

Emergency Maintenance

Although very little effort is required on a day-to-day basis, there will be times that emergency maintenance is necessary. This effort usually requires more than one person, particularly when it involves searching for a malfunctioning valve. Many times problems develop after normal working hours, requiring personnel to be called out on an overtime basis. Emergency or breakdown maintenance can occur in the piping system, at the vacuum station, or at the vacuum valve.

Vacuum Station

Malfunctions at the vacuum station are generally caused by pump, motor, or electrical control breakdowns. Redundancy of most components allows for the continued operation of the system when this occurs.

Collection System Piping

Assuming proper design and construction, there is very little physically that can go wrong in the piping system. Occasionally, a line break will occur, due to excavation for other utilities or landslides, causing a loss of system vacuum. By closing and opening division valves in a logical sequence in key areas along the piping route, the operator can easily isolate the defective section.

Other potential problems include system waterlogging or even a complete loss of vacuum that renders the entire collection system inoperable. Fortunately, these instances are very rare and usually short-lived. The *AIRVAC Installation, Operation and Maintenance Manual*³ provides detailed procedures for correcting these system anomalies.

Vacuum Valves

Most emergency maintenance is related to malfunctioning vacuum valves caused by either low system vacuum or extraneous water. While failure of the valve is possible in either the open or closed position, virtually all (99%) occur in the open position.

When open-position failure happens, a loss of system vacuum occurs, as the system is temporarily open to atmosphere. The fault monitoring system will recognize this low vacuum condition and alert the operator of the problem. A common cause of failure in this position is the entrance of extraneous water into the controller.

Valve failures, if not located and corrected quickly, may cause failures in other parts of the system. A valve that is hung open or that continuously cycles will cause system vacuum to drop. If the vacuum pumps cannot keep up with this vacuum loss, the result is insufficient vacuum to open other valves. This may lead to backups. When vacuum is finally restored, a large amount of sewage, in relation to the amount of air, will be introduced into the system, possibly resulting in waterlogging.

A valve failing in the closed position will give the same symptoms as a blocked gravity line, that is, the customer will experience problems with toilet flushing or backup of sewage on the property. A phone call from the affected party makes identification of this problem easy.

Some systems in Europe have used individual, hard-wired alarms at each valve pit. This practice is not done in the U.S., as the costs of such systems generally outweigh the benefits, especially considering the increased reliability of the modern vacuum valve. Future vacuum systems may include a wireless alarm system, as there has been some recent progress in the development of such systems.

D. Spare Parts Inventory

Valves and Valve Pits

For optimum operating efficiency, it is necessary that a sufficient inventory of spare parts be kept. Some of the spare parts, such as fittings and pipe, can be purchased through local builder's supply companies. However, there are parts that are unique to vacuum systems that cannot be purchased locally. For convenience, these spare parts many times are included as part of the construction contract.

Table 11 is a recommended list of spare parts. As previously described, faulty valves and controllers are not repaired in place, but rather are removed and replaced with a spare. The rebuilding procedure is then done at the maintenance facility. The 3% spare valves and controllers and rebuild kits shown in Table 11 are for this purpose (i.e. – for emergency maintenance).

The spare parts in Table 11 are not intended for use in the wholesale rebuilding of valves and controllers that is associated with the preventive maintenance program. For that, inexpensive rebuild kits are typically purchased by the operating entity prior to this scheduled maintenance.

Table 11

Spare Parts List Per Every 100 System Valves

Quantity	Part
3 ea	3" Vacuum Valve
3 ea	Sump breather unit assembly
3 ea	Sump breather installation parts bag
3 ea	Controller
3 ea	Controller rebuild kit
6 ea	3" No-hub couplings
1 ea	3/8" clear vacuum tubing (6 ft long)
1 ea	5/8" clear vacuum tubing (12 ft long)
3 ea	3" grommets
3 ea	6" grommets
6 ea	Vacuum valve rebuild kits
12 ea	Controller mounting O-Ring
2 ea	Tube controller grease
4 ea	Tube vacuum valve grease
3 ea	Surge suppressor
12 ea	Tubing clamps
3 ea	Controller mounting key
3 ea	Cycle counters

Vacuum Station

The vacuum station also requires spare parts. These range from spare pump seals to fuses. Specialty items that should be considered are given in Table 12.

Table 12

Vacuum Station Spare Parts

Quantity	Item
15 gal	Oil
1 ea	Overhaul kit (vacuum pump)
1 ea	Filter Kit (vacuum pump)
1 ea	Motor-pump coupling set (vacuum pump)
1 ea	Seal kit for sewage pump
2 ea	Motor coupling (sewage pump)
1 ea	Gasket set (sewage pump)

Special Tools

In addition to spare parts, certain specialty maintenance tools and equipment are needed and are listed in Table 13.

Table 13	
Specialty Tools and Equipment (1 set per Project)	
Quantity	Item
1 ea	Portable vacuum chart recorders
100 ea	Vacuum charts
3 ea	Chart pens
2 ea	0-20 in W.G. Magnehelic gauges
1 ea	0-50 in W.G. Magnehelic gauges
1 ea	Sensor pipe puller
1 ea	Valve repair stand
1 ea	No-hub torque wrenches
1 ea	Vacuum gauges
1 ea	Controller test box

E. Record Keeping

Good records are important for the efficient, orderly operation of the system. Pertinent and complete records provide a necessary aid to control procedures as they are used as a basis of the system operation. The first step of any troubleshooting procedure is an analysis of the records. A wealth of information is contained in the basic records.

Records should be kept on all normal, preventive and emergency maintenance as well as on operating costs. These should be preserved and filed where they are readily available to operating personnel. All records should be neat and accurate and made at the time the data are obtained. It is good practice to summarize this data in a brief monthly report and a more complete annual report. Ideally, the information can be entered into a computer program that can be accessed prior to the O&M staff initiating a call.

Normal Maintenance Records

The following information should be recorded on a daily basis:

- Date & weather conditions
- Personnel on duty
- Routine duties performed
- Operating range of vacuum pumps
- Run-times of vacuum pumps, sewage discharge pumps & generator
- Flow data
- Complaints received and the remedies
- Facilities visitors
- Accidents or injuries
- Unusual conditions
- Alterations to the system

Preventive Maintenance Records

Adequate records provide information that tells operational personnel when service was last performed on each system component and indicates approaching service or preventive maintenance requirements. Efficient scheduling of these maintenance tasks can be made which avoid interference with other important aspects of system operation.

Results of periodic inspections should be kept. This would include a list of all potential problems, the likely cause of these problems, the repairs necessary to solve the problem, and recommendations for future improvements to minimize recurrence.

Emergency Maintenance Records

Records should be kept concerning all emergency maintenance, including:

- Date and time of occurrence
- Person(s) responding to problem
- Description of problem
- Remedy of problem including total time to correct problem
- Parts and equipment used
- Recommendations for future improvements

Operating Cost Records

To insure budget adequacy, it is very important to keep accurate information concerning the costs of all operation and maintenance items. Costs include:

- Wages and fringe benefits
- Power and fuel consumption
- Utility charges
- Equipment purchases
- Repair and replacement expenses
- Miscellaneous costs

F. Operation and Maintenance Manual

To properly operate a vacuum sewer system requires proper training. Operation and Maintenance (O&M) Manuals are a vital part of this training process. Problems arose in some of the early vacuum systems due to the lack of such aids. Manufacturers and engineers are now recognizing this fact and are reacting accordingly with improved technical assistance and O&M Manuals.

While an O&M Manual is a valuable tool, it should not be viewed as the ultimate solution to every problem. The efficiency of the system depends on the initiative, ingenuity, and sense of responsibility of the system's operation/maintenance staff. Also, the manual should be constantly updated to reflect new operational experience, updated equipment data, and previous problems and implemented solutions. Typical information that should be contained in the O&M Manual includes:

- Design data
- Equipment manuals
- Shop drawings
- Permits & Standards
- Operation & Control information
- Personnel information
- Records
- Preventive maintenance schedules
- Emergency operating & response program
- Safety information
- Utility listings

IV. SYSTEM O&M COSTS

A. *Basis of O&M estimating charts*

Fifteen years ago, very little historical O&M cost data existed on vacuum sewers. This lack of data led many to the conclusion that vacuum sewers must be O&M intensive. A review of operating records of systems discussed in this chapter suggests that previously published O&M figures may no longer apply. Reasons for this are twofold. First, the previous figures were based on very limited data on a few early systems. Second, component improvements have resulted in significantly fewer service calls and lower O&M costs.

The U.S. EPA did a study on alternative collection systems, including vacuum sewers, in 1989 and 1990. Part of this effort included visits to operating systems in order to obtain information on operation and maintenance costs. The report containing this information, called the *Alternative Wastewater Collection Systems Manual* (EPA/625/1-91/024) was published in 1991.

It is important to note that a wide variety of projects were visited by EPA, including some of the earliest systems built, as well as systems that utilize design concepts and system components other than those used by modern systems. As one would expect, the earliest systems had the highest O&M costs (see Section II for discussion).

Design advancements coupled with component improvements have led to modern vacuum systems that are operated at much higher levels of reliability than their predecessors.

Information from the 1991 EPA Report, as well as information from recent (post-1990) systems gathered from the 2003 Operator Survey was used in the formation of the estimating tables that follow. For each particular O&M item, a cost range is given. With proper design, installation, and maintenance, the O&M costs at lower end of the cost range can be achieved.

B. *Operation and Maintenance Cost Estimating*

A discussion of the typical O&M cost components that must be considered follows.

Labor

To estimate labor costs, the number of person-hours required is multiplied by the hourly rate. Fringe benefits are then added. The annual person-hour requirements are made up of normal, preventive, and emergency maintenance. Judgment must be exercised in interpreting other projects for use in labor estimates (*see box below*).

For most systems normal maintenance does not require an operator 24 hours a day. Monitoring of the system is provided by the telephone dialer/telemetry system. However, someone must at least be on call around the clock in case the telephone dialer calls with a problem. In this respect, vacuum systems are unique. Very few problems in a vacuum system can go uncorrected for any length of time without causing a cumulative effect. Therefore, rapid response time is a key requirement.

Typically, the normal workforce does preventive maintenance during off-peak working hours. As such, preventive maintenance is usually reported as normal maintenance.

EFFORT TO OPERATE A SYSTEM ACTUAL VS. BILLABLE TIME

The operating Utility's overall responsibilities should be considered when estimating labor costs. For example, the Utility is likely to be responsible for other sewage treatment/disposal facilities, and possibly even water facilities. In these cases, operating personnel are usually shared. At the end of the year, the time charged to the operation of the vacuum system will relate exactly to the effort required (e.g., one (1) hour per day for each vacuum station plus some hours charged to other preventive and emergency maintenance). If the overall facilities are large enough to warrant more than one shift, emergency work most likely will be done without overtime being required.

An entirely different situation exists for the Utility operating nothing but a vacuum system. Typically, a full-time operator is hired. This person charges 8 hours a day to the maintenance of the system although most days he will spend much less than this. Should a problem develop after normal working hours, he most likely will be paid overtime. Even though the primary operator and part-time operator assistants will spend the same amount of actual vacuum sewer maintenance time as the staff with broader responsibilities above, the amount of billed time will appear be entirely different.

The engineer should carefully analyze the client's overall management responsibilities, taking into consideration the possibility of shared duties, prior to making an estimate of the labor costs.

Emergency maintenance many times requires personnel after normal working hours. The result is overtime pay. Emergency maintenance typically requires two operators or one plus an assistant.

Table 14 provides a range of labor hours required per year. These factors were based on an analysis of the O&M data from the 2003 Operator Survey described in Section II, which included systems of all ages, including some of the earliest systems. The mid-range values shown in Table 14 represent the average of all of these systems, while the high and low values shown have been slightly modified to correct for unusually low or high figures that could skew the analysis. The values shown should be considered as realistic estimate for new systems with proper design, construction, and management.

Table 14						
Labor Estimating Factors (Based on 2003 Operator Survey)						
	Vacuum Station (hrs/yr/station)		Vacuum Mains (hrs/yr/system)		Vacuum Valves (hrs/yr/valve)	
	Range	Mid-range	Range	Mid-range	Range	Mid-range
Normal	100 - 400	250	20 - 40	30	0.20 - 0.80	0.50
Preventive	20 - 80	50	10 - 30	20	0.20 - 0.60	0.40
Emergency	<u>20 - 40</u>	<u>30</u>	<u>5 - 15</u>	<u>10</u>	<u>0.20 - 1.00</u>	<u>0.60</u>
TOTAL	140 - 520	330	35 - 85	60	0.60 - 2.40	1.50

When a full-time operator is to be hired, regardless of anticipated workload, the values in Table 14 should not be used. In this case, the estimated annual person-hour requirements should include the full-time hours of employment plus an estimate of the overtime (emergency maintenance) hours, taking into consideration overtime work generally requires two people. No allowance is needed for normal or preventive maintenance since these tasks can be performed during normal working hours.

Power

Power is required for the vacuum pumps, the sewage pumps, and the heating, lighting and ventilation of the vacuum station. For planning purposes, values shown in Table 15 can be used to estimate the annual power consumption for the vacuum station.

Similar to the economy of scale in capital cost, there is an economy of scale pertaining to power costs. The smaller vacuum stations typically have the highest power consumption per connection and the larger vacuum stations have the lowest power consumption per connection.

Table 15			
Vacuum Station Power Consumption Estimating Factors			
	Range (KwHr/yr/conn)	Monthly Cost @ \$0.08/KwHr	Monthly Cost @ \$0.10/KwHr
Low	200	\$1.33/mo/conn	\$1.66/mo/conn
High	400	\$2.66/mo/conn	\$3.34/mo/conn
Ave	300	\$2.00/mo/conn	\$2.50/mo/conn

Utilities

Utilities at the vacuum station generally include water, telephone, and fuel. Water may be required for sinks and hose bibs. A telephone is required for the fault monitoring system. Fuel may be required for the standby generator. The cost of these utilities generally is less than \$85 per month (4th qtr 2006).

Clerical

This item includes wages for the clerical staff as well as billing costs such as envelopes and stamps. Like labor costs, the value of this item most likely will depend on whether the operating Utility has an existing, ongoing operation which requires office staff. If so, the total costs need to be allocated between the administrative responsibilities.

Transportation

Vehicle expenses to maintain the system will be incurred. For estimating purposes, a mileage rate multiplied by the estimated annual miles will suffice. This rate should include vehicle amortization, depreciation, taxes, and similar expenses.

Supplies/Maintenance

As with a conventional system, certain supplies will be required. Restocking of spare parts and inventory is included in this item, as are oil, fuses, charts, and chart pens. Initial purchase of items on quantity discount should be maximized to take advantage of the lower unit costs when compared to subsequent prices for replacement.

Service contracts for emergency generators, as well as fuel for the generators, may also be included in this item.

Miscellaneous Expenses

Miscellaneous expenses include insurance and maintenance on the system structures as well as professional services (engineering, accounting, legal) that may be required during the year.

Equipment Reconditioning and Replacement

A set-aside account should be established to generate sufficient funds on an annual basis for major equipment reconditioning and replacement. The annual cost of these needs is initially estimated by dividing the replacement cost by the useful life. This amount is generally set-aside in an interest bearing account until needed. Present dollars can be used in the estimate since the interest earnings most likely will offset inflation. Alternative methods dictated by regulatory agencies also can be employed. This annual cost estimate should be reviewed regularly to assure that sufficient funds are available to keep the systems running optimally. Table 16 lists the major equipment items and their useful life.

Table 16			
Typical Reconditioning & Replacement Costs For Major Equipment (4 th qtr 2006)			
	Cost range *	Expected Life (yrs)	Annual R&R (\$/yr/sta)
Vac Pumps (2)	\$10,000-\$34,500	15-20 yrs	\$ 500-\$2,300
Discharge Pumps(2)	\$ 6,000-\$19,200	15-20 yrs	\$ 300-\$1,280
Collection Tank	\$ 5,000-\$11,000	25-50 yrs	\$ 100-\$ 440
Control Panel	\$ 5,000-\$21,200	20-25 yrs	\$ 200-\$1,060
Misc equip	\$ 2,000-\$ 3,300	15-20 yrs	<u>\$ 100-\$ 220</u>
		TYPICAL RANGE	\$1,200-\$5,300

* function of equipment size

Valves and controller can be rebuilt very inexpensively (see Preventive maintenance section). For this reason, R&R funds are not required for total replacement, but rather just for the rebuild costs. Table 17 shows these operating costs.

Table 17			
Typical Rebuilding Costs For Valves & Controllers (4 th qtr 2006)			
	Cost range	Rebuild frequency (yrs)	Annual R&R (\$/yr/valve)
Vacuum valves	\$27.00-\$38.00	8 -12 yrs	\$2.25 - \$ 4.75
Controller	\$27.00-\$38.00	4 - 6 yrs	<u>\$4.50 - \$ 9.50</u>
		TYPICAL RANGE	\$6.75 - \$14.25

V. SYSTEM MANAGEMENT CONSIDERATIONS

A. Sewer Authority Responsibilities

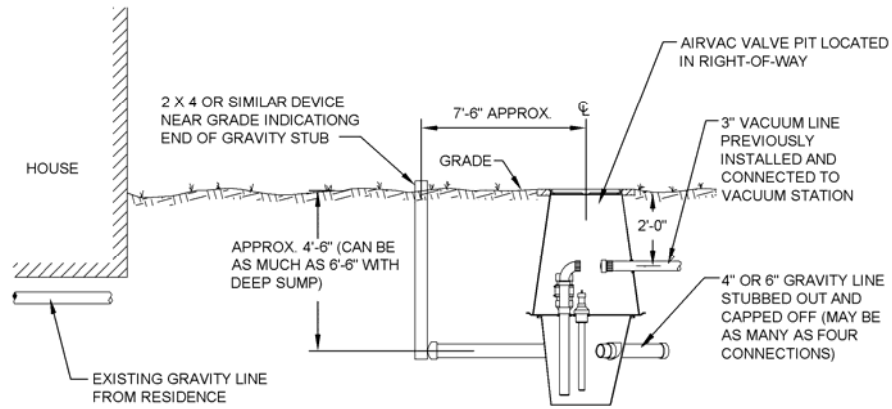
Customer connection to system

Table 18 shows the normal sequence of events, from construction of the system to home-hook-up. Note that the contractor does not install the vacuum valve during the construction phase (see discussion later in this section). When all contractual obligations are fulfilled, the system is accepted by the Utility and the homeowners are notified that the system is ready.

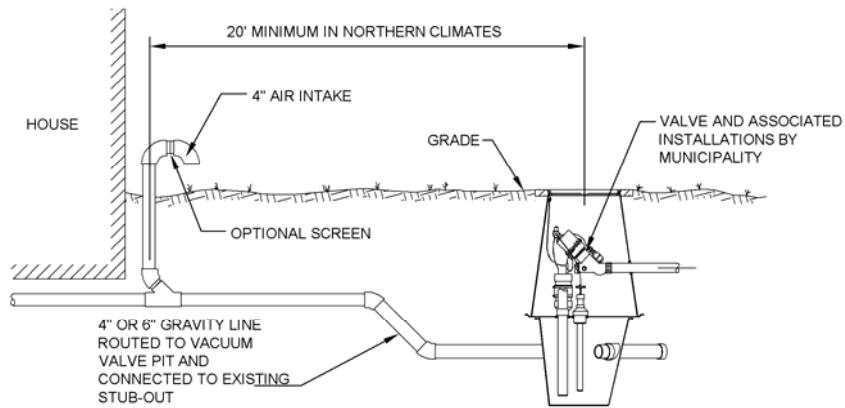
Table 18	
Normal sequence for connection	
Tasks	Responsible party
Lines, pits & vacuum station installed	Installation Contractor
Final 4 hr vacuum test & line flushing	Installation Contractor
System acceptance & notification to homeowners that system is ready	Utility
Building sewer & air intake installed	Homeowner's plumber
Vacuum valve installed	Utility

Recommended: Utility installs the vacuum valve after construction phase

The vacuum valve is not installed until the customer is ready to connect to the valve pit setting (see Figure 1). It is common for the contractor to install the valve pit/sump, including all of the necessary piping, during collection system construction. The valve is supplied to the Utility for their installation at a later date. In this manner, the Utility can systematically install the valves as each customer requests connection.



VALVE PIT INSTALLATION PRIOR TO HOME CONNECTION



VALVE PIT INSTALLATION WITH HOME CONNECTED

Figure 1
Valve Pit Installation
(Courtesy AIRVAC)

Not recommended: Installing the vacuum valve during construction phase

In an effort to relieve the Utility from installing the vacuum valve, some engineers set up their bid documents to require the Contractor to install the vacuum valve during construction. This is not recommended for the reasons shown in Table 19.

Table 19	
Potential Problems If valve is installed during construction phase	
Potential Problem	Reason
Pit collapse or implosion	Cycling the vacuum valve without the homeowner's building sewer and 4-inch air intake installed can result in the bottom sump collapsing. This would require the pit to be re-excavated and replaced.
Difficulty assigning blame if 4 hr vacuum test fails	The intent of the final 4-hour vacuum test is to test the contractor's workmanship in installing the vacuum lines. Testing with the valve in place introduces one more variable: the valve may leak. Failure due to a leaking valve is not the contractor's responsibility.
Homeowner may illegally hook-up early	With a complete system available, the homeowner may connect to the valve pit without the Utility's knowledge. This action would preclude the Utility from doing the normal inspection of the homeowner's gravity lateral, air intake, etc. This could lead to some serious problems such as sump collapsing, I&I problems, water in the controller, etc.

A further complication may occur if a failed vacuum test is due to a combination of a valve leaking as well as a line leak(s). This could cause some real difficulties in troubleshooting to determine where the problem really is and in subsequently assessing liability. Contractor liability versus manufacturer liability is clear-cut when the testing is done without the valve in place.

Operating personnel

Once all customers are connected, the Utility's only focus should be providing reliable, efficient service to their customers. To achieve this, the operating personnel must be capable, dependable, and knowledgeable. Of utmost importance is attitude. An operator that does not believe in the system will ultimately cause the system to operate below its potential, in terms of reliability and costs. Conversely, one with a good attitude uses creativity to get more out of the system than was originally planned.

Sewer Use Ordinance

To operate any system at a high level of efficiency requires a Sewer Use Ordinance. This document sets consistent rules for all users to follow. Included are material specifications, minimum slope requirements and air-intake locations for the building sewer. Of extreme importance to the Utility is a limitation of use of the vacuum sewer to convey sanitary wastes only, as extraneous water (illegal discharges or I/I) will cause operational problems.

An active program for the identification of extraneous water sources should be developed. This may include smoke testing and dye testing, but the simplest approach to quantify sources of extraneous water in a vacuum system is to use cycle counters. This device, when connected to an interface valve, will record the number of times the valve opens in a given period. Knowing that each cycle is approximately 10 gallons, the Utility can estimate, based on water consumption records, the number of cycles expected over that period. A count significantly in excess of the expected number of cycles usually implies that extraneous water is entering the system.

The Utility's other major concern during this full-operational phase is its responsibility for future extensions of the system. This includes proper planning, design, and construction of such extensions. Utility, in accordance with the provisions of the Sewer Use Ordinance, is also responsible for implementing future connections to the existing system.

Private vs Public ownership of equipment serving house

There are two issues to consider: 1) actual **ownership** of the valve/valve pit and 2) **maintenance** the valve/valve pit. In the case of vacuum systems, the valve and valve pit are both owned and maintained by the public operating Utility as discussed in the following paragraph.

Because of the “system” nature of vacuum sewers, the maintenance of a vacuum system, including the valve pit and the valve, must be done by the Utility. Improper maintenance at a single valve pit could affect the entire system, including the line hydraulics and the operation of the station. Obviously this would jeopardize the system and affect other customers. So, it is not prudent to put this in the hands of the homeowner. The only way to guarantee maintenance of the valve and valve pit is by the Utility actually owning it.

B. Homeowner Responsibilities

The homeowner's responsibility usually begins at the end of the valve pit stub-out and includes the building sewer, the air intake and any in-house needs.

Most Utilities require the homeowner to replace the building sewer from the house foundation to the stub-out connection, since vacuum sewers are not designed to handle extraneous water. By accepting old, possibly defective building sewers, the Utility would be taking a serious risk on increased operation and maintenance problems.

The homeowner is also responsible for the installation of the 4-inch air-intake. The air-intake is necessary for the proper operation of the valve. It is desirable for this to be located against a permanent structure, such as the house itself, a fence, or a wall.

All of the work required by the homeowner must be inspected by the Utility prior to final connection. This ensures the proper and efficient operation of the system. Compliance with the Sewer Use Ordinance is the only remaining user responsibility. Typical requirements include that the homeowner should not drive or build over the valve pit, and should protect the facilities from damage. Discharge of flammables, acids, and excessive amounts of grease, sanitary napkins, or other non-sewage items is forbidden. This requirement differs little from user ordinance requirements for conventional sewers. Proper use of the system results in lower user charges and improved reliability.

C. Other Entities

During the planning, design, and construction of wastewater management systems, there are many different entities involved. Two vitally important ones are the regulators and the engineer. It is during these times that critical decisions are made and details finalized.

Engineer

Historically, engineers have often viewed the startup of a wastewater system as their final involvement. While this attitude is economically understandable, it is not acceptable where local management programs are minimal. Continuing involvement should be provided to help the Utility develop an experience base with newer systems that permits intelligent applications in the future.

The engineer should spend a significant amount of time assisting the Utility during the startup of the system. Tests should be run and problems simulated to see if the system is operating as designed. On a regular basis (often annually), the operating records should be analyzed for budget sufficiency purposes. Institution of EMS practices can assure that any problems and their solutions will be identified and addressed by the Utility. In short, the engineer should be prepared to assist the Utility in using the operating experience of the system to help develop improvements in future designs.

Regulatory agencies

Likewise, regulatory agencies must, as part of their oversight responsibilities, be aware of the potential impacts of the operation of a new collection system on environmental compliance of the entire wastewater management program. Information on problems, including causes and the remedies, should be gathered by the Utility for review by the regulatory agency. Cost and other data should be obtained and used accordingly by the regulators in counseling future potential users of this type of collection system.

It is this present lack of useful capital and operational costs and other pertinent information that causes many engineers and regulatory agencies to shy away from new technologies. Continued use of conventional solutions that are well known and codified is far easier for regulators and engineers than seeking lower-cost, new solutions to solve wastewater pollution problems. Therefore, implementing new solutions, no matter how cost-effective, will continue to be difficult.

D. Education Process

Prior to 1990, very little written documentation existed on vacuum sewers. Much of the recent growth in the vacuum sewer industry can be attributed to the ever-increasing amount of information regarding the technology. Sources of this information can be found in technical presentations, papers that have been presented at conferences, articles that have appeared in trade journals, and factory & project tours.

Papers and trade journals

Since 1990, there have been several papers on vacuum sewers presented at the Water Environment Federation's (WEF) annual conference as shown on Table 20.

Table 20			
Papers on Vacuum Sewers Presented at WEF Conferences since 1990			
Feature Project	Year	WEF Conference	Primary Author
Update of Operating Systems	1990	Washington, DC	Rich Naret, P.E. Cerrone & Associates
Salmon Beach, WA	1991	Toronto	George Norby, P.E. PEI Barrett.
Queen Anne's Co, MD	1993	Anaheim	Gary Moore Queen Anne's County
Albuquerque, NM	1994	Chicago	E.D. Whitis, P.E. HDR
Englewood, FL	1997	Chicago	Jonathan Cole, P.E. Giffels-Webster
Beach Road MUD, TX	2000	Anaheim	George Neill, P.E. Neill Engineering
Provincetown, MA	2002	Chicago	James Sullivan, P.E. Metcalf & Eddy
Plum Island, MA	2002	Chicago	Theresa McGovern Camp Dresser & McKee
Sarasota Co, FL	2003	Los Angeles	Dan Burden, Ph.D, P.E. Hazen & Sawyer
Vashon Island, WA	2003	Los Angeles	John Wilson, P.E. PEI Barrett
Plum Island, MA	2004	New Orleans	Don Mauer, P.E. Camp Dresser & McKee
Albuquerque, NM	2006	Dallas	Robert Paulette, P.E. Wilson & Co

Most of the major trade journals have published articles on vacuum sewers. These include Water Environment & Technology (WE&T), Public Works, Civil Engineering, Civil Engineering News (CE News), Government Engineering, Underground Construction, Land Development Today and the National Small Flows Clearinghouse (NSFC).

Technical presentations

For consultants and prospective system owners to learn more about vacuum sewer systems, vacuum manufacturers typically provide technical training through presentations. These presentations range from planning (vacuum basics) to detailed design to construction and O&M.

Factory and project tours

In addition to the technical seminars, vacuum manufacturers also conduct factory tours and tours of operating systems. The intent of the factory tour is to increase the comfort level of those considering the use of vacuum technology. Specifically, the factory/project tour does the following:

- Provides a basic understanding of vacuum sewer system principles.
- Demonstrates the actual components used in a real system.
- Provides participants with firsthand knowledge of vacuum systems by visiting those who've designed, constructed, and operated these types of systems.

The primary reason for a Utility or its engineer to attend a factory/project tour is to find out firsthand whether or not they, as responsible officials, can recommend this technology for their particular situation. Feedback from these groups indicates that the visit to the factory and/or an operating system ultimately allowed them to make an intelligent, educated decision.

References

1. B.C. Burns et al. *Method and Apparatus for Conveying Sewage*. Patent No. 3,730,884, May 1, 1973.
2. *Alternative Wastewater Collection Systems*. EPA/625/1-91-024, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1991.
3. AIRVAC Operation, Installation & Maintenance Manual, Rochester, IN., 2005.