



# Vacuum Sewers 101

An Online Continuing Education Course for Engineers

**Course Number: EN-4019**

**Credit: 4 Hours / 4 PDH / 4 CPD**

# Vacuum Sewers 101

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## I. INTRODUCTION

### A. *History of Alternative Collection Systems (ACS)*

In the late 1960s, the cost of conventional gravity collection systems in smaller communities was found to dwarf the cost of treatment and disposal. The capital cost of conventional collection systems was averaging almost four times the cost of treatment, and operation and maintenance costs followed a similar pattern because of the greater number of lift stations required per unit length of pipe, owing to the increased lengths of pipe needed to service these less-densely populated areas. In response to these problems, efforts were initiated by the public and private sectors to develop low-cost collection systems that could serve the needs of rural communities that constituted over 80 percent of the communities in need of wastewater collection and treatment.

At that time, there were only two wastewater options available to rural populations: conventional sewers and centralized wastewater treatment or unmanaged individual home septic systems. The problem was approached from two directions. First, intensified research was initiated to develop and evaluate onsite wastewater systems that could overcome site and soil limitations. Second, new wastewater collection approaches that were less costly were also being developed and evaluated. Today, this array of low-cost sewers conveying wastewater to distributed treatment systems and various alternative and advanced onsite systems are known collectively as “decentralized wastewater technologies.” The collection systems typically are called “alternative collection systems” (ACS). One of these, vacuum sewers are the focus of this course.

Initial demonstration projects for ACS technologies were funded by the U.S. Environmental Protection Agency (USEPA) and its predecessor agencies, and the Farmers Home Administration (now the Rural Utilities Service of USDA). Because of the promise shown by these technologies, they were given special status for increased federal cost-sharing under the innovative and alternative (I&A) technology provisions of the Clean Water Act of 1977. Thus stimulated, these technologies flourished in small communities, which were able to secure grants under this program. More than 500 alternative collection systems (ACSs) were installed under the I&A provisions, and a significant number have also been constructed with state, local, and private funding since that time.

The federal Construction Grants Program was terminated and evolved into the State Revolving Fund (SRF) Program as the 1990s began. Although the inherent value of these systems in small communities and certain sections of larger urban areas was recognized by several practitioners, reductions in available grants and the slow rate of incorporation into engineering education programs caused a slowing in the rate of ACS applications. However, where communities had the foresight to compare the present worth of these technologies to conventional sewerage without federal grants, the economic benefits were obvious. The primary disincentives were the lack of familiarity by engineers with these technologies, public perception of these systems as “temporary substitutes for a real sewer,” and a paucity of grant funding for communities willing to adopt these systems. However, in 1997 the USEPA issued a report (EPA/832/R-97/001b) entitled “Response to Congress on Use of Decentralized Wastewater Treatment Systems.” This report was directed by Congress in response to the same concerns over the high cost of conventional sewerage to solve wastewater problems and the efforts of the Rural Electric Cooperatives and other interested parties to undertake the management of rural wastewater systems, thus allowing the use of more advanced wastewater systems, including alternative collection systems, to better serve rural America’s needs.

The report clearly stated the value of the decentralized approach in rural and peri-urban areas to make necessary improvements in wastewater infrastructure more affordable. It added the emphasis that these technologies must be properly managed in order to provide the level of performance required. The decentralized approach to wastewater management was described to include onsite systems, cluster systems, and mixed solutions under a competent and empowered centralized management program, similar to what has historically been necessary for conventional sewer systems. More recently, the term “distributed wastewater management” has been adopted to better describe the need for centralized management of all wastewater (and even all water-related) systems.

This report stimulated new federal programs, both within USEPA and through directed Congressional funding, to identify, investigate, and minimize the barriers to full consideration of this approach. The Water Environment Federation (WEF) has been involved in several of these efforts, and the creation of a new manual (WEF MOP FD-12) is part of those activities. Some noteworthy examples of barriers include local rules that prohibit the use of any collection technology other than conventional gravity sewers by local agencies, engineering consultants that steer clients away from alternative collection systems (ACS) through ultraconservative cost estimating owing to their unfamiliarity with the technology, and federal and state funding programs whose rules penalize use of any unconventional technology by applicants.

Because of their relative newness, all ACS types, including vacuum sewers, have suffered from some cases of misdesign, misinstallation, mismanagement, misuse and misapplication, as have all new technologies. Because they are still not

generally included in mainstream engineering education, they are still dismissed by engineers who are fearful of new concepts with lower capital costs and operator/managers who have had no management training specific to these systems. The purpose of the WEF MOP FD-12 manual is to provide information that will help overcome these concerns and to facilitate consideration of these technologies to solve existing wastewater problems and reduce the cost of wastewater management for new developments.

## **B. History of Vacuum Systems**

The use and acceptance of ACS have expanded greatly in the last 40 years. One of these, vacuum sewers, has been used in Europe for over 100 years, although this technology has only been in the United States since the late 1960s.

Vacuum sewer collection systems were patented in the United States in 1888. The first commercial applications of such systems were by the Liljendahl Corporation (now known as Electrolux) of Sweden in 1959. Several other companies have since entered and contributed to this market, both in the U.S. and worldwide.

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

The 1991 EPA Manual, *Alternative Wastewater Collection Systems*<sup>1</sup>, characterized vacuum sewers as lagging behind other collection types. This was a fair assessment at that time but is no longer true as the vacuum type now viewed on par with other system types. The lessons learned from the early systems resulted in better design and operation guidelines. Advancements in the technology, coupled with system component improvements, have led to more reliable, efficient systems. Finally, awareness of the technology and its limits has been raised through the process of educational seminars, papers and, magazine articles. All of these factors have led to an increased comfort level with vacuum technology.

## **C. Comparison to other system types**

Each section of the WEF MOP FD-12 manual is concerned with a specific ACS technology. Each cites a series of site conditions that favor that technology over conventional gravity sewers. Not surprisingly, that list is somewhat similar for all ACS types considering the variety of commonalities they share. Only a few site and management conditions clearly favor a given type of ACS over the others. The reason why one ACS technology has been chosen over the others for the case

studies presented in that manual is rarely, if ever, due to careful and comprehensive evaluation of all ACS technologies and subsequent comparison. Usually, the engineer involved has some familiarity with one type of ACS and attempts to make a comparison against conventional sewerage. Depending on how well that is performed, the availability and rules of financial assistance programs, and the municipality's stated desires, a system is chosen. As incomplete as that appears to others, it is still well beyond the typical facility plan that compares only a few treatment options, with collection and dispersal already assumed.

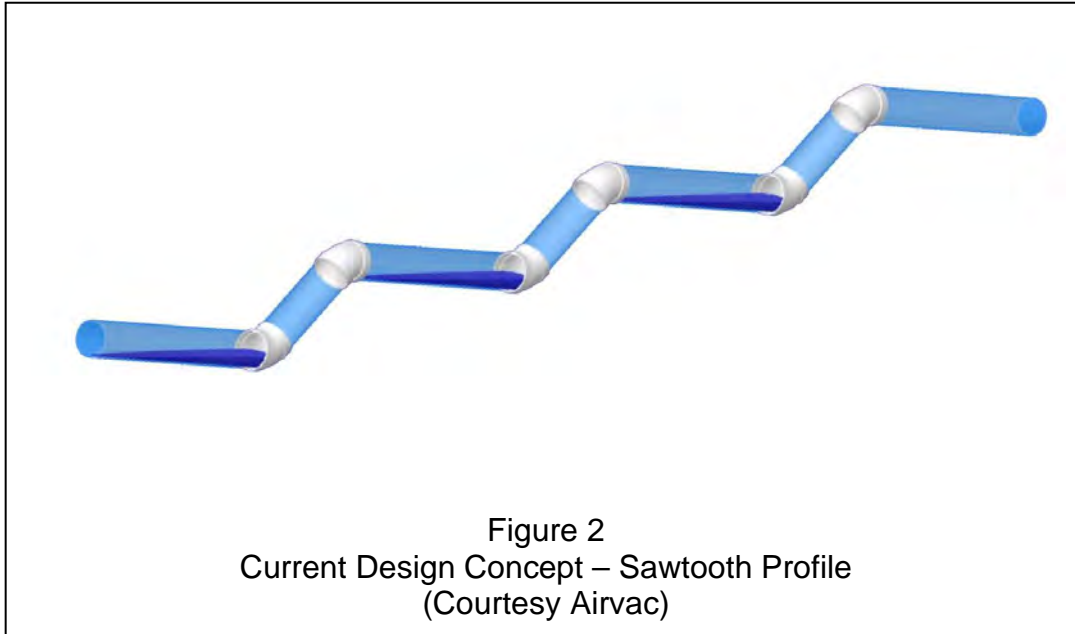
## **II. HOW IT WORKS**

### **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 a 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.

The exact principles of operation of a vacuum sewer system are somewhat empirical by nature. An early concept centering on liquid plug flow assumed that a wastewater plug completely sealed the pipe bore during static conditions. The movement of the plug through the pipe bore was attributed to the pressure differential behind and in front of the plug. Pipe friction would cause the plug to disintegrate, thus eliminating the driving force. Therefore, reformer pockets were located in the vacuum sewer to allow the plug to reform by gravity and thus restore the pressure differential (Figure 1). In this concept, the re-establishment of the pressure differential for each disintegrated plug was a major design consideration.

In the current sawtooth profile design concept, the reformer pockets are eliminated so that the wastewater does not completely fill or "seal" the pipe bore. Air flows above the liquid, thus maintaining a vacuum condition throughout the length of the pipeline (Figure 2). In this concept, the liquid is assumed to take the form of a spiral, rotating, hollow cylinder. The momentum of the wastewater and the air carries the previously disintegrated cylinders over the downstream sawtooth lifts. The momentum of each subsequent air/liquid slug and its contribution to the progressive movement of the liquid component of the previous slugs are the major design considerations.



Both of the above design concepts are approximations and oversimplifications of a complex, two-phase flow system. The character of the flow within the vacuum sewer varies considerably. The plug flow concept is probably a reasonable approximation of the flow as it enters the system, whereas the progressive movement concept is more likely a better approximation of the flow throughout the vacuum main.

The reformer pocket concept, used in all of the early U.S. systems, gradually gave way to the sawtooth profile concept. Since the early 1980s, virtually all systems in the U.S. have been designed using the sawtooth profile.

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

Figure 3 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

#### **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 4). In this case, the point of connection is the valve pit.

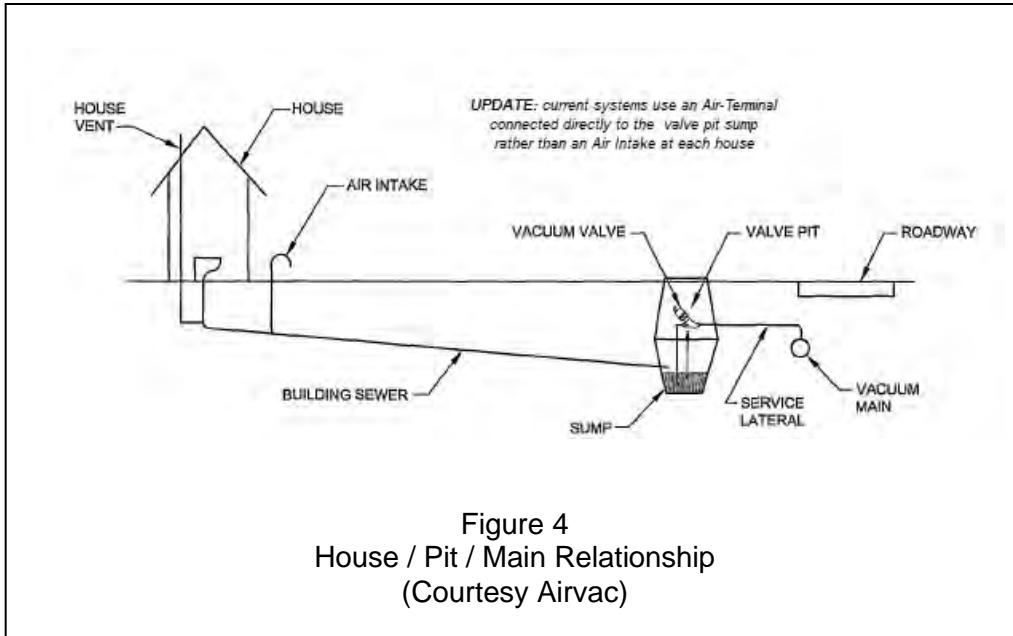


Figure 4  
House / Pit / Main Relationship  
(Courtesy Airvac)

**In the valve pit**

Vacuum created through the vacuum between gravity

Housed in the to normally closed in maintained on the

The lower chamber house. When 10 g automatically open valve opens and in stays open for anc system. This air co Terminal device loca pit sump.

station is transferred is where the interface

valve. This valve is ure that vacuum is

sewage from the the interface valve ing required. The uated. The valve air to enter the house or an Air- ectly to the valve

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