ABSTRACT

Siphons, sometimes called depressed sewers or sags, allow wastewater to flow through a pipe under low lying areas or obstructions such as rivers, utilities, or other obstructions, where flow by gravity at these locations is impossible. The flow through a siphon is driven by a difference in hydrostatic pressure without the need for pumping. A major drawback with siphons is foul odor created from the displaced air flow at upstream siphon structures. The evacuation of air occurs during the transition from gravity flow in the upstream wastewater main to pressure flow in the siphon.

Siphons are commonly used in combination with an air jumper or an odor control design methodology, such as carbon filters or scrubbers. Air jumpers are air pipes used to prevent sewer headspace pressurization within the pipeline and capture odorous sewer gasses which help to maintain the sewer ventilation within the pressurized siphon. Air jumpers span the length of the siphon from box to box. Another method of odor control is the use of liquid phase or vapor phase treatment, which work to treat and control the escape of these gases and odors to the atmosphere.

Although there have been a few research papers, guidelines, and “rules of thumb” published, there is not an abundance of industry information available on the design of siphons in combination with air jumpers. However, for air jumpers, there are practical concepts of fluid mechanics that need to be followed in order for the process to work. In other cases, liquid or vapor phase systems are used for odor control, or no odor control system is implemented at all.

This paper discusses the various guidelines or “rules of thumb” and empirical data/criteria for air jumper design including fluid/air flow characteristics, minimum pipe size, velocities, and other assumptions, as well as the pros and cons of using air jumpers versus other odor control methods. Another focus of this paper is to provide analysis through case studies including the design and construction of siphons with air jumpers and odor control systems as well as the addition of air jumpers to existing siphons in the form of a retrofit replacement. Advantages and disadvantages of constructability, operations, and maintenance of the air jumper and odor control system designs will also be presented.

KEYWORDS

Sewer, Siphon, Odor Control, Air Jumper
INTRODUCTION

There are various design methods and owner preferences for siphon design and odor/air control. The purpose of this paper is to provide general guidelines for siphon design, a discussion of air flow considerations with regards to odor control in sewers, and comparisons of odor control methods including liquid-phase and vapor-phase treatment. This paper also includes case studies that have implemented various odor control methods.

Several published sources provide design guidelines on siphon design and hydraulics; however, there are more limited resources of published guidance on mitigation of odors at siphons. There is a shortage of information, especially regarding estimation of upstream air flow and volume which is a key component to sizing odor control systems. For this paper, several published sources were reviewed including published books, reports, studies, and conference papers. Through this research, several “Rules of Thumb” regarding air flow in collection systems emerged. As suggested in several published sources, there is still a research gap on the subject and more industry research is needed.

METHODOLOGY

Siphons

Siphons are used to allow a liquid, in this case wastewater, to flow through a pipe under low lying areas or obstructions such as rivers, streams, dips in elevations, railroads or other utilities, where flow by gravity is impossible. Siphons achieve flow due to the difference in hydrostatic pressure, eliminating the need for pumping. The flow changes from upstream gravity flow to pressurized flow through the siphon sections. Generally, siphons are not preferred unless absolutely necessary for grade issues because of the maintenance requirements. As such, access points and provisions need to be included in design to allow for periodic maintenance.

Regulatory agencies typically require two or more siphon barrels, usually sized to handle low and high flows. This allows for one barrel to be temporarily shut down for servicing and cleaning. Normal flow is diverted to one barrel with a typical minimum pipe diameter of 6-inches. Lastly, a minimum flushing velocity of 3 fps at initial and design flows is recommended. Flows into the siphon barrels are commonly controlled with upstream weirs.

Understanding Air Flow

One challenge with siphons involves the air that is displaced as the liquid enters the pressurized section of the pipeline. The only way for air to escape is to exit the inlet siphon structure through vents or at upstream manholes. To prevent vapor lock, vents are required at the downstream end of siphons which allow air to be pulled back in to the gravity system. If upstream vents are located in highly populated areas, odors can be a concern. Odors are particularly problematic during lower flows when the formation of hydrogen sulfide is more prevalent.

The first step of odor control is determining the upstream air flow characteristics. This starts with an analysis of many complex physical variables including friction drag, wastewater level within a pipe, temperature, and barometric pressure. High wastewater flows tend to produce a greater frictional drag which leads to greater air movement. Airflow velocity is highly dependent on depth and velocity of the liquid (Pescod, 1981), which is greatly variable for most WW collection systems that have diurnal patterns that correspond to wastewater usage.

Air flow calculations are made more complex by vertical drops, junction and diversion structures, siphons, and pump stations. However, there are many different methods and opinions in the

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wastewater industry on how air flow velocities should be determined. There are several “Rules of Thumb” suggested in available industry design guidance (WEF, 1983; Clow, 2004) that suggests three common ideas: (1) airflow velocity will be 35% - 50% of liquid velocity in a 1/2 full pipe, (2) maximum airflow is at 1/2 full pipe because surface exposure is maximized above the headspace, and (3) very slow velocity moves small volumes of air. Recent reports and industry guidance suggest that much more research is needed to develop better understanding of air flow within collection systems.

**Odor Control**

Odors in collection systems are typically handled in one of two ways: liquid-phase or vapor phase treatment (Landers, 2007). Liquid-phase treatment such as chemical injection, nitrate salts, and iron salts helps to inhibit odors by preventing the formation or removing Hydrogen Sulfide (H2S) from the pipeline. H2S is formed by the bacterial breakdown of organic material in the sewage. The H2S gas reacts with moisture in the pipe to form sulfuric acid which leads to corrosion of the top of the pipe. The formation of H2S can be prevented with nitrate salts. Alternatively, iron salts remove H2S that is already present in the wastewater. Another liquid phase treatment method is to inject oxidizers (hydrogen peroxide, sodium hypochlorite or potassium permanganate) but this method requires more space for equipment and is better suited for a treatment plant or lift station site.

Odor control using vapor phase treatment, prevents odors from exiting the collection system. This method is common for upstream siphon head structures where pressurization and odor release occurs. There are several alternative treatments including activated carbon and wet chemical scrubbing. Activated carbon is widely used for treating odors in simple collection systems, and it is often used at lift stations, siphons, and manholes. Carbon canisters require less maintenance than some alternatives, but an electric power source is needed to operate the vent fan. Wet chemical scrubbing using sodium hypochlorite and sodium hydroxide is a viable alternative method, but there are strict safety requirements for transportation, handling and storage. Due to the safety requirements, this method may be better suited for secured wastewater treatment plant (WWTP) site or lift station site.

Another vapor phase treatment method used exclusively for siphons is an air jumper. This alternative uses a separate air pipe parallel to the siphon barrel(s) to convey air from the gravity pipe to the downstream end of the siphon. Other odor control approaches include Bio-filters, Bio-scrubbers, and other methods better suited to WWTP or pump station sites due to footprint and maintenance and security requirements. When selecting an odor control method, owners and designers should consider the cost, size and footprint of the alternative, location, maintenance and security requirements, and the specific application.

**Air Jumpers**

As stated previously, an air jumper is a pipe that is usually installed parallel with the siphon barrels. This separate air pipe directs the air from the inlet structure to the outlet structure of the siphon. The entrance and exit of the air pipe is installed at higher elevations than the wastewater hydraulic grade line (HGL). On long siphons, a fan is sometimes needed to force airflow through the jumper pipe.

Design and operational challenges with air jumpers include condensate that may collect in the lower elevations of the air jumper. Another concern involves wastewater surcharge and overflow events that can increase the risk of liquid filling the air pipe. Liquid in the pipe could create an air-lock prohibiting conveyance of air downstream and causing increased odor issues. To counter these issues, an access manhole or sump pump is needed to periodically remove the accumulated condensate. Additionally, an under-sized air pipe can cause odor problems since it
would not allow the full air volume to flow downstream and would then escape at the upstream manhole.

The size of the jumper pipe is determined on a case-by-case analysis for each siphon and collection system. Sizing of the pipe is dependent on upstream airflow, which as previously discussed is highly variable and difficult to accurately calculate. More research is needed to develop a set of industry guidelines for designing air jumpers. The limited design guidance leaves only “Rules of Thumb” to estimate airflow and air pipe sizing: typically size the jumper pipe to be 1/2 of the diameter of the largest siphon barrel (WEF, 1983).

A nomograph method (Deering, 2005) is the only published air jumper sizing guidance that uses more detailed variables than commonly used rules of thumb. This guidance determines air flow rates using a reduction factor (RF) which is a measured ratio of the headspace airflow rate to WW flow rate. The theoretical maximum air flow rate with depth-to-diameter value is 0.3. Then the air jumper diameter should be selected from the ASHRAE Handbook of Fundamentals nomograph for headloss due to friction through steel ducts. A headloss rate of 0.01 feet per 100 feet is recommended. Headloss within the overall air jumper system (pipe friction plus minor losses) should be analyzed to confirm total headloss does not exceed 0.01 inches of water column.

**DISCUSSION**

For this paper, two case studies involving siphon design and odor control were reviewed.

**Case Study #1**

The first case includes a large river crossing using double barrel siphons as shown in Figure 1. The large and small siphon barrels were constructed using 60-inch and 36-inch reinforced concrete pipe. The siphon barrels were installed by open cut crossing of the river. Since it was a river crossing, the barrels were concrete encased and included drilled piers for foundation support. Grouted weirs at the upstream siphon structure were designed to control low and peak flows entering the siphon.

![Figure 1: Case Study #1, Siphon Section View](image_url)
Early in the project design phase, odor issues were recognized as a potential challenge. The upstream siphon is located in a city park with a heavily used hike and bike trail. This location has a higher chance of causing an odor nuisance to public users of the park. Four 8-inch vents were installed at each of the upstream and downstream siphon structures to vent air. With the many variables involved with estimating upstream air flow and odor generation at specific locations, the owner chose to install the siphon first without implementing an odor control system. This strategy allowed for measurement actual air volume and odor levels and installation of an odor mitigation system to match actual field conditions.

Soon after construction was completed and the siphon was in operation, there were numerous odor complaints from park users. The owner installed an activated carbon system which included carbon canisters connected to the upstream siphon vents. Activated carbon canisters was a preferred option for the owner at this location because the siphon is located in close proximity to a WWTP site that allows for maintenance personnel to easily monitor and maintain the system. Since the odor control system has been installed, the odors have been minimized and complaints from park users have been reduced.

**Case Study #2**

The second case involves replacement of over 1,000 linear feet of existing sagged sewer pipe for a low water crossing. The existing 48-inch sanitary sewer main had failed in several locations and was in need of an emergency replacement. The existing sag in the pipeline was replaced with a double barrel siphon. The project was located under an existing roadway within an apparent 60-foot wide right-of-way. The roadway is approximately 30 feet wide with a 16-inch water main, 8-inch gas line, underground telephone, and overhead electric within the ROW on one side and overhead electric and trees on the other side. There is approximately 8 feet from the edge of pavement to the power poles.

A double barrel siphon was designed based on current and future flows for average dry and wet weather conditions. The siphon was sized with a 30-inch FRP large barrel, and a 16-inch PVC small barrel, along with an air jumper pipe. Due to the limited space available in the right-of-way and depth of the existing sewer, the trench configuration and air jumper design had to be considered. The typical pipe trench of siphon section can be seen in Figure 2.

![Figure 2: Case Study #2 Siphon Trench Section View](image-url)
The owner chose to use an air jumper as a result of previous good results with other recent siphon replacement projects in the system. Other odor control methods were eliminated as options due to the limited space in the road right-of-way. Several published design guidelines were used to determine the appropriate air jumper size. Using the “rule of thumb” of half the size of the largest siphon barrel indicated a required 15-inch diameter air jumper pipe. As a second check, the ASHRAE Nomograph method (Deering, 2005) was also used to determine the necessary air pipe diameter. The nomograph method suggested an 18-inch diameter air jumper pipe would be needed for this siphon configuration. Knowing that determination of upstream air flow volume is complex and difficult to determine, the air jumper in this case was conservatively sized with an 18-inch diameter pipe. The siphon and air jumper has been in operation for nearly two years with no reported odor issues.

CONCLUSIONS

Odor will be a challenge at the upstream end of sewer siphons. This can be an especially sensitive challenge for locations near residential or other populated areas and should be addressed early during project design. One method is to handle the odor at the source by preventing the H2S from escaping and treating it, or by preventing the H2S from forming in the system. Another method is to send the air downstream with the wastewater flow through an air jumper pipe.

Determining the upstream airflow is the key to sizing the air jumper pipe or other odor control systems. Unfortunately, the determination of air flow is complex and has many variables which require a case-by-case analysis to determine the appropriate size and capacity needed for the odor control system. Based on recommendations in current industry literature, more research is needed on airflow dynamics in wastewater collection systems. As a practical approach for design engineers, it is recommended to use multiple calculation methods to cross-check the design and choose the most conservative approach to prevent odors in wastewater collection systems.

REFERENCES


