Siphonic Roof Drainage Systems

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Siphonic roof drainage systems were introduced in the late 1960s in Finland. The pipes used in these systems are sized to completely charge the system to full-bore water flow capacity during a rainstorm. The system's advantage is in its use of the maximum head possible from the water-entry height to the vertical pipe-discharge location. Specially designed roof outlets are required to achieve siphonic action with full-bore pipe flow into the horizontal collectors and stack. Negative pressures in the vertical-pipe water column accompany siphonic action.

A siphonic roof drain requires a special insert that acts as an air baffle and anti-vortex vane so that only water, not air, is drawn from the roof. The outlet (i.e., the rainwater collector) leads to horizontal collector pipes, installed without pitch, which connect to vertical downpipes, from which the water is discharged at atmospheric pressure. Extreme rainfalls may require conventional overflow drains or weirs (as required by many building codes).

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Siphonic systems sharply contrast with conventional rainwater roof-drainage piping systems, which include airflow capacity allowance for partially filled vertical stacks.

Engineered Design of a Siphonic System

In Europe, siphonic systems have been installed in buildings that cover a large area, such as airports, covered malls, warehouses, and factories. What is especially beneficial in these types of buildings is that several roof drains can be connected to a horizontal pipe (without pitch) that feeds rainwater into a vertical pipe at any architecturally or otherwise suitable location (e.g., built structure perimeter envelope).

Engineered design methods must be applied to each installation. Standard published information or computer aids are not adequate for selection of the elements. Specific local rain-loading conditions (i.e., weather-based rain data) also must be incorporated. As noted by almost all manufacturers and suppliers, appropriate engineering design, including application of correct calculation methods, is essential as the basis of a siphonic system.

The historical basis of model-code tables for rainwater area collection and runoff is derived from the Manning formula. The Manning formula calculates open-channel water-flow, which is velocity driven by the horizontal pitch (based on $V = k_1 R_h^{2/3} S_{1/2}$) where V is the velocity, k_1 is a constant based on the roughness of the pipe, R_h is the hydraulic radius, and S is the slope). Although coupling to downflow in vertical, partially filled stack annular pipe-flow sizing (with air and water sectors in the pipe cross-section) requires nearly atmospheric pressure to maintain fixture-trap seals, such pressure conditions are not required for storm-water drainage applications.

Application of pipe-flow theory to a siphonic roof drainage system requires analysis based on the Bernoulli principle (in consistent dimensional units) for single-phase flow. This relationship sets potential energy from the elevation difference between the roof outlet and the point of discharge equal to disposable head from kinetic energy with all energy losses from friction loss dependencies on the Reynolds number, pipe-surface roughness. Detailed analysis of the variables and parameters that control flow conditions are necessary. In this engineered design method, it is not possible to obtain accurate flow-energy loss estimates based on approximations of equivalent lengths. Here, fundamental parameters for detailed systems analyses must be applied, including physical phenomena only determinable from basic theory of the physics of flow.

$$\left|\frac{P}{\rho}+\frac{V^2}{2g}+Z\right|_1 = \left|\frac{P}{\rho}+\frac{V^2}{2g}+Z-\sum h_f\right|_2$$

Roof outlet *Point of discharge*

Fitting and elbow losses can be determined from the Darcy-Weisbach equation. They are summed from

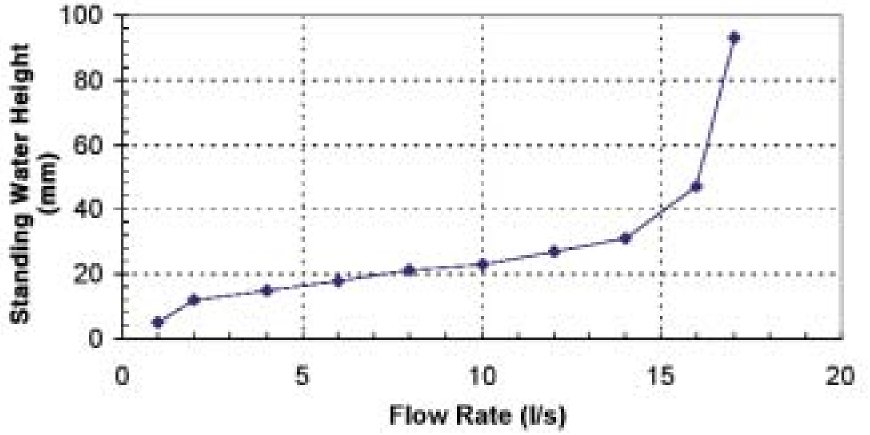
$$h_f = f\left(\frac{L}{D}\right)\frac{V^2}{2g}$$

for the system elements, where h_f = friction head, f is the friction factor, L = developed length of pipe, D = diameter of pipe, V = flow velocity, and g is the gravitational constant.

Atmospheric pressure prevails at the gutter surface above the roof outlet, while reduced pressure prevails inside the piping to the discharge location. The total energy available to the system is equal to the potential energy from the elevation difference between the roof outlet and the point of discharge. The kinetic energy induced in the system by conversion from potential energy results in an energy loss from friction and fitting effects.

The final design configuration sets a full-bore flow rate that is fixed, regardless of rainfall intensity. (The local building code typically defines the highest rainfall intensity that must be accommodated.) The likelihood of excess-rainwater roof build-up requires that an overflow protection technique be applied—either an accepted architectural practice such as a scupper or an innovative method. Conditions in the system are a mixture of air and water when rain occurs at less than design. Pressures remain essentially at atmospheric because annular or partially filled pipe flow occurs. The horizontal pipe flow at partially filled flow depths is driven by incoming energy, and gravity drives the annular downflow in vertical stacks.

Figure 1. Capacity of Siphonic Rainwater Outlet



From R. Hanslin (Geberit AG) (1993, September), Siphonic rain water drainage system. Presented at Centre Institute de Batement W62 Symposium, Water supply and drainage for buildings, *Porto, Portugal.*

Flow Conditions

When the system is fully primed, water velocity sweeps debris out of the pipe. **Figure 1** illustrates increases in full-bore siphonic flow rate as water depth increases. With a lower flow rate, the system entrains air into the outlets and carries it through the pipe system.

An approximate method of calculating pressure drop has been developed to account for partial air volumes. The measurements of different entry-fitting designs in various flow conditions permit correlations (usually by fitting equations) to be developed for performance factors applied to acceptable engineered approximations. Usually such techniques use dimensional analyses of complicated interactions of fluid phenomena with particular hardware designs, then generalize them by data-fitting relationships. Most manufacturers have developed computer-aided design tools, based on empirical test results, for application to two-phase flow conditions of water-air fraction.

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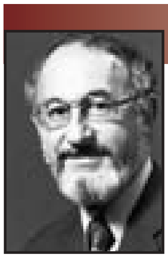
Mechanical Failures

At low flows, air and water are separated in the pipe, so partially filled pipe flow occurs, and distinct free-surface flow occurs in the horizontal pipes. With increasing water inflow, air entrainment occurs in various forms (e.g., bubbles are drawn along water surfaces, "trapped separated volumes" are entrained in the flow). For low-intensity rainfalls, below the system design, the roof drains perform in a conventional manner. At increasing rain intensity, partial depressurization of the system occurs.

Tests have shown that under such circumstances, substantial air can be drawn into the system. It can exceed water inflow, resulting in unsteady water flow and air conditions. In detailed dynamic test measurements, these events appear almost cyclic. They generate noise with system structural vibration. The result can be physical failure of pipes or components due to reduced pressure loads that exceed the wall-strength limits of the materials. Vibration-induced failure can be caused by frequent excitation from near-cyclic reduced-pressure variations.

Full-bore flow generates substantial, near-steady negative pressures, with high drainage flow rates caused by the stack full-bore flow. With properly sized outlets, air is restricted from entering with the roof rainwater into the horizontal piping and vertical stack. The maximum capacity of the fully primed hydraulic system is achieved in balance with hydraulic resistance without air. However, that steady state of reduced pressure can cause pipe-wall collapse.

The next review will present several issues related to negative pressures and system dynamics of unsteady pressure effects as well as elements from system research on transient effects from priming action. ■



Lawrence Galowin is retired from the National Institute of Standards and Technology (NIST) and is now a NIST guest researcher. He is a member of the American Society of Plumbing Engineers, the American Society of Mechanical Engineers, and the National Plumbing Standards Committee (A112). Before retirement he was senior program manager at NIST; earlier he directed the building services system that included plumbing research activity. With Prof. J.A. Swaffield, he is co-author of The Engineered Design of Building Drainage Systems (1992).