Technical paper

Principles of siphonic roof drainage systems

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Abstract

In this article it has been illustrated that a siphonic roof drainage system with a single roof outlet is reasonably well understood. The governing equations are presented. The basic design of the system can be determined using single phase flow theory assuming full bore flow of the system. The start up and two phase flow functioning of the system are more complex. In a multiple roof outlet siphonic system the interaction between the roof outlets makes it very complex and only skilled people can design a well functioning system.

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Introduction

For drainage of large roof areas a siphonic system is a well acknowledged cost saving solution. The principle of expelling air from the system means that only water is being transported at high speed making use of the suction pressure created behind the full bore water column. The high speed full bore flow makes smaller pipe dimensions than in conventional systems possible.

Also the elimination of multiple downpipes and a lot of piping in the groundwork mean a large cost saving and more architectural freedom for the building design.

The only disadvantage is that one has to have a better technical background to be able to properly design a siphonic system. A multiple roof outlet siphonic system is a complex system that needs to be carefully optimized to function properly.

In this article the theory of a single roof outlet siphonic roof drainage will be explained to give a basis for the principles of a multiple roof outlet system.

Principle of syphonic roof drainage

The principle in syphonic roof drainage is the full bore flow of the system. One thus has to obtain and maintain a full bore flow for optimal functioning of the system.

The full bore flow is initiated by the hydraulic jump (see figure 1) at the entrance of the horizontal part of tail pipe or collector pipe of the system. The shape of the hydraulic jump depends on 2 parameter:

- the velocity of the flow streaming into the horizontal pipe
- and the resistance of the pipe beyond the entrance of the collector pipe.

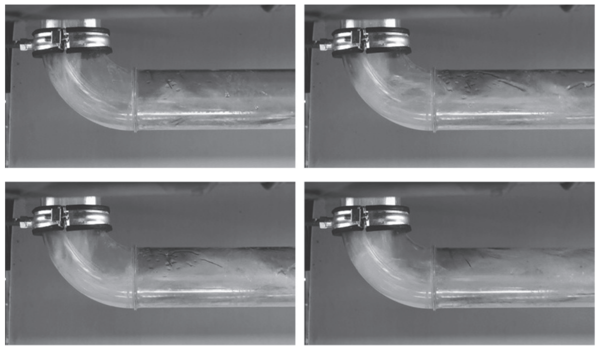

Figure 1.
Forming of the hydraulic jump at start up of siphonic roof drainage system

The principle can be compared to the stream of vehicles on highways or race tracks. Vehicles can accelerate optimally on roads that are straight and keep on being straight for miles. As soon as there is a curve in the road the vehicles have to slow down. When the first vehicle decelerates the one behind him has to decelerate also and the distance between the vehicles is decreasing. This is very often the moment for accidents to happen: there is an increasing chance for collision. Exactly this is the case for fluid particles in a stream. When particles are redirected from the vertical downfall to horizontal flow the fluid is decelerated. As fluid particles have no brakes they will collide and the only way they can go is up, creating height and thus a hydraulic jump. The above explains 2 things: first of all why an increasing length of vertical tail pipe leads to earlier priming, second why an increasing resistance in the collector pipe leads to this same result. An increasing length of tail pipe leads to more time to accelerate the fluid coming from the roof, thus to higher velocities in the bend to the horizontal pipe. This will lead to a higher hydraulic jump when the flow is decelerated in the horizontal pipe. Also the more the flow is decelerated in the horizontal pipe, thus the higher the resistance downstream of the bend, the higher the hydraulic jump will be. The higher the hydraulic jump is the earlier the full pipe diameter will be closed off by water and priming will start. When the horizontal pipe is (slightly) inclined the water will run off easier and thus the hydraulic jump will be less pronounced, delaying the onset to priming of the system.

Theoretical background

In fluid dynamics the Navier-Stokes equations are the general form of the momentum equations that account for fluid motion and are written as:

$$\frac{D\rho\vec{V}}{Dt} = \rho\vec{g} - \nabla p + \mu\nabla^2\vec{V}$$

For incompressible inviscid flow they become:

$$\rho\frac{D\vec{V}}{Dt} = \rho\vec{g} - \nabla p$$

and are known in this form as Euler's equations.
The headloss ΔH is defined as:

$$\Delta\mathrm{H} = \frac{p}{\rho g}$$

Substituting this in the above Euler's equations and dividing by ρ gives:

$$\frac{D\vec{V}}{Dt} = \vec{g} - g\nabla H$$

In streamline coordinates along the x-axis and taking the z-direction the direction of gravity:

$$\frac{D\vec{V}}{Dt} = \frac{\partial V_x}{\partial t} + V_x\frac{\partial V_x}{\partial x} = -g\nabla z - g\nabla H =$$
$$-g\cdot\sin\beta - g\frac{\partial H}{\partial x}$$

With a constant diameter of the pipe and thus constant cross section, A, this can be further rewritten to:

$$\frac{D\vec{Q}}{Dt} = \frac{\partial Q}{\partial t} + \frac{Q}{A}\frac{\partial Q}{\partial x} = -A\cdot g\nabla z - A\cdot g\nabla H =$$
$$-A\cdot g\cdot\sin\beta - A\cdot g\frac{\partial H}{\partial x}$$

with β the angle between the streamline x and the direction perpendicular to the gravity (β positive when the streamline ascends).

For a descending collector pipe the angle β thus is negative, the term with this parameter thus positive, driving the speed in the collector pipe up and thus making it decelerate less, producing a less pronounced hydraulic jump and thus delaying priming (full bore flow) in the system.

In a steady incompressible inviscid full bore flow integration of Euler's equations over a streamline gives the well known Bernoulli equation:

$$\frac{p}{\rho} + gz + \frac{V^2}{2} = const$$

This equation is often referred to to easily explain the principle of siphonic roof drainage.

The head loss in pipe systems consists of losses due to the friction coefficient of the pipe walls, losses due to the fittings (bends, knees, T-pieces and the roof outlet) and losses due to the additional roughness caused by welding of pipes and fittings.The head loss due to friction along the pipe walls can be described by the equation:

$$H = f\frac{L}{D}\frac{V_x^2}{2g}$$

with f the friction factor. For the determination of the friction factor the Colebrook-White equation is most widely applied:

$$\frac{1}{\sqrt{f}} = 0.25\left[\log\left(\frac{k_s}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)\right]$$

with k_s the equivalent sand grain roughness. A good estimation for f is:

$$f_0 = 0.25\left[\log\left(\frac{k_s}{3.7D} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^{-2}$$

The head losses of fittings and roof outlets can be approximated in a similar way by:

$$H = \xi\frac{V_x^2}{2g} = f\frac{L_e}{D}\frac{V_x^2}{2g}$$

with ξ a coefficient specific for each fitting of a certain diameter and Le an equivalent length of pipe.

Conclusion

In this article it has been illustrated that a siphonic roof drainage system with a single roof outlet is reasonably well understood. The governing equations are presented.

The basic design of the system can be determined using single phase flow theory assuming full bore flow of the system. The start up and two phase flow functioning of the system are more complex.

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