

Flow phenomena of a siphonic roof outlet

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Abstract

So far the investigations on siphonic roof drainage systems have been focused on the functioning of the system as a whole. In this report the focus will be on the roof outlet and the phenomena observed during tests in a test rig according to the EN 1253 and ASME A112 standards for roof outlets. This comprises the test of a single roof outlet in a siphonic configuration.

The primary goal of the tests was to design a well-functioning all plastic improved roof outlet, which is currently in production.

During the tests some remarkable phenomena typical of siphonic roof outlets were observed, that will be presented in this report.

It appeared that air ingress follows a path of decreasing size of air pockets (plugs to bubbles), followed by a decrease in number of bubbles. The noise level produced by the roof outlet is correlated with this phenomenon.

Further it was observed that a disc alone is not sufficient to keep the air out of the system and that additional measures, like fins on top of the air baffle, are necessary to prevent the development of large vortices that are capable of dragging air in to the system.

Also it was observed that waves reflect from the edges of the disc and fins of the air baffle leading to an interference pattern of waves around the roof outlet.

It was observed that the air is still being sucked in from a certain discharge rate after the water level has reached the height of the disc of the air baffle. At first large plugs of air are being dragged in, but with increasing water level the plugs become bubbles decreasing in size and increasing in number. The noise level appears to be correlated to this phenomenon.

Finally a "pumping" behavior was observed at the outlet when having become siphonic that is probably correlated to instabilities of the flow at the exit of the pipe system.

1. Introduction

Siphonic roof drainage systems are gaining more and more ground in the drainage of rain water from large flat roofs because of their cost effective, space saving design and high performance. Significant work has been done by several institutes to describe the principles of the system.

The design of the siphonic roof outlet on top of this system has not been investigated this intensively thus far. Therefore tests have been performed with our in-house test rig to gain insight in the principles of the roof outlet design leading to the development of an all plastic siphonic roof outlet for roof drainage systems exceeding all requirements of the EN and ANSI standards and the build up of a vast knowledge of the functioning of a siphonic roof outlet.

The tests have been performed in a single roof outlet siphonic configuration.

On top a special component has been developed to use the roof outlet in an emergency roof outlet configuration as well without a significant decrease in performance compared to the standard roof outlet. In this paper the phenomena observed at the siphonic roof outlet will be described one by one.

First of all the siphonic roof drainage system itself and its components will be described in paragraph 2.

Then in paragraph 3 the basic working principle will be described.

Following in paragraph 4 the flow phenomena occurring at the roof outlet will be described.



Illustration 1. Test rig

2. Siphonic roof drainage system and its components

A siphonic roof drainage systems consists of one or more roof outlets [1] followed by an equal amount of vertical tail pipes [2] which leads the flow into a horizontal collector pipe [3] that ends in a vertical fall pipe [4] (see illustration 2). As stated before the tests have been performed on a single roof outlet configuration. The emergency roof outlet has also been tested as a single roof outlet configuration, thus not in conjunction with a regular roof outlet system.

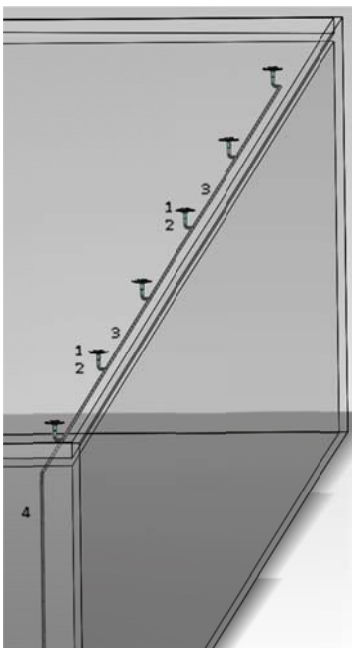


Illustration 2. Siphonic roof drainage system

The roof outlets form the entrance from the roof to the pipe system. The tail pipes guide the water down to the collector pipe, which is not only collecting the water from all roof outlets but also guides it horizontally to one side of a building, where the fall pipe transports it downward towards the sewer.

The roof outlet consists of a roof plate [A], a so called air baffle [B] and a connector to attach it to the pipe system [C] and possibly a leaf guard [D] (which in our design has been integrated in the air baffle design [B]). Illustration 3 presents the roof outlet and its components.

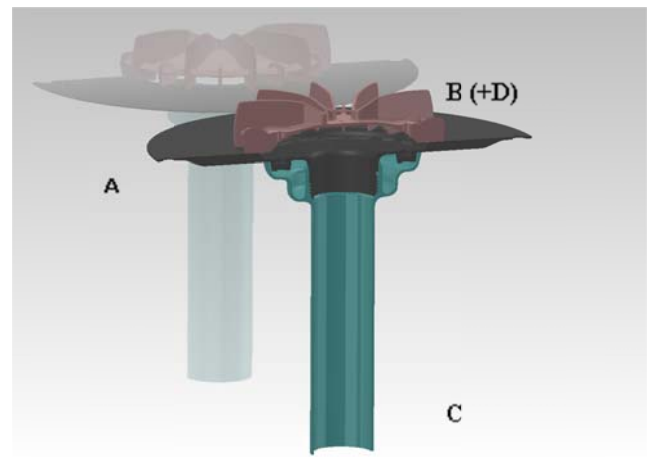


Illustration 3. Siphonic roof outlet

The roof plate is a specially designed plate with a hole with smoothly rounded edges, which is the opening to the pipe system. The air baffle is mounted over the opening in the roof plate to prevent air from being drained into the pipe system (as will be further explained in a following paragraph). The connector is mounted on the bottom part of the roof plate to connect the roof plate to the pipe system. The function of the leafguard is to keep out rough sized debris that can possibly block the system.

3. Working principle of the roof drainage system

The siphonic roof drainage system is based on the principle of full bore flow. This means that the system is designed to obtain a flow through the system that fills the whole diameter of the pipe, thereby creating a vacuum upstream dragging more water in from the roof, thereby reaching a high discharge rate through a relatively small diameter pipe system. To obtain a full bore flow the water must be forced to fill the whole diameter, which can be done by decelerating it, e.g. in a horizontal collector pipe, which leads to a so called hydraulic jump, that can force the flow to fill the whole diameter of the pipe (see illustration 4).

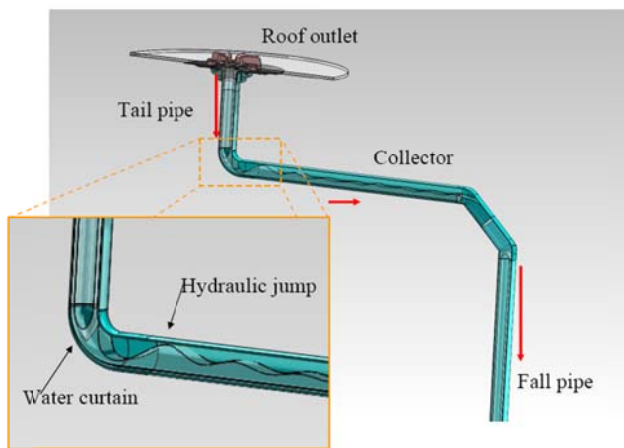


Illustration 4. Working principle of siphonic roof drainage system

The hydraulic jump is like the piling up of cars in a traffic jam after a slow turn in the highway. The water curtain at the end of the tail pipe and the flow through the elbows before the fall pipe is characterized by a ventilated mixture of water and air as long as the flow has not become siphonic.

The gravity driven flow in the fall pipe accelerates the flow, and after becoming siphonic drags the water down functioning as the engine of the system.

So the water falling down the tail pipe, accelerating on its way down, is being decelerated in the collector pipe to make it flow full bore when enough water is discharged through the pipe system and is being accelerated in the fall pipe.

When the hydraulic jump is able to fill the pipe diameter the water will try to force out the air in front against the upward buoyancy forces of the air while filling the tail pipe upstream at the same time. This process is called priming.

The system is already functioning as a siphonic system when about 60% of the system is filled with water. The air is still present then, but the system is no longer ventilated from top to bottom and thus the water falling down creates an underpressure, sucking in more water from the roof.

The siphonic roof drainage system must be designed such that a once a year rain storm can be transported from the roof before the roof construction is endangered. This is done by a proper choice of pipe diameters in the system. This also means that the system will work conservatively (carrying air) for most regular rainfall events and siphonically on some cases of heavy rainfall.

In case of more extreme rain storms an emergency roof drainage system must come into play to drain the excess of rainwater up to a maximum sum falling during a once in a 100 year rain storm. The exact numbers for rainfall intensity for and capacity of a regular and emergency system and the allowable water levels on the roof can differ from country to country.

4. Flow phenomena at the roof outlet

The roof outlet must prevent air from entering the siphonic roof drainage system to initiate full bore flow while having as less resistance to the system as possible to obtain a maximum discharge flow and minimum water height on the roof.

4.1 Air ingress

When there would not be an air baffle, the water that is being dragged down the pipe system would drag air along at the water surface.

The water will accelerate towards the roof outlet. The velocity component of the surrounding water will increase with the decrease of the radius around the

$$v = \frac{Q}{2\pi R \cdot h_{water}}$$

roof outlet (Following Bernoulli's law the increasing velocity towards the pipe system will mean the waterheight will be decreasing towards the pipe

$$\frac{p}{\rho} + \frac{1}{2}v^2 + g \cdot h = const$$

(since and thus h will decrease with increasing v under the condition of atmospheric pressure at the surface). The water flowing towards the pipe system will drag air along at its surface, dragging it into the pipe system.

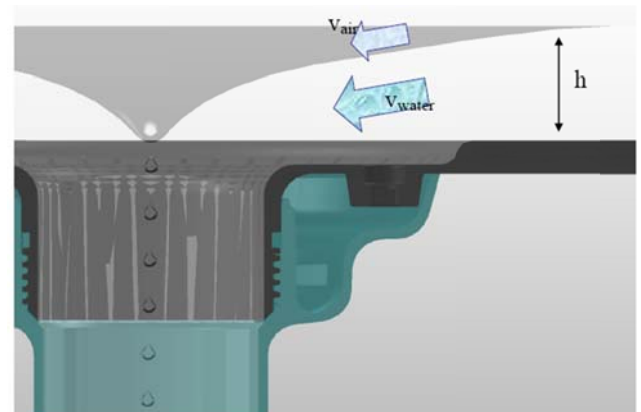


Illustration 5. Air being dragged in with the flow of water

In theory this would be a symmetric situation occurring equally from all directions. In practice small disturbances (both in the construction of the roof outlet, water flow and in environmental air flow) will lead to a swirling flow towards the pipe system (vortex creation) similar as the vortex seen when emptying a bathtub.

4.2 Air baffle design

To prevent air from being dragged in a disc could be mounted on top of the pipe system. This will stop the air from being dragged in with the water flow. Unfortunately this will not be sufficient, since the water will still swirl around the disc and create a vortex that drags in air underneath the disc. A vortex accelerates the flow with a maximum in its center, creating an under pressure. By Bernoulli's Law again this means the water surface is lowered, which can result in a local dip that creates the opportunity for air to find its way underneath the roof outlet.

Fins are necessary to break the vortex formation up in smaller vortices that are not strong enough to drag in air underneath the disc.



(a) no disc or air baffle, large vortex



(b) disc, vortex at edge of disc (ink injected)



(c) disc with fins, no vortex (ink injected)

Illustration 6. Roof outlet with no disc (a), with disc (b), with disc with fins (c)

4.3 Phenomena typical for siphonic roof outlets

Using a disc shaped air baffle design with fins leads to some specific phenomena.

As soon as the water level around the air baffle reaches the disc of the air baffle (note that the water level is decreasing towards the air baffle and thus the overall water level is higher) the water will close off the path for air to enter the system. Due to under pressures increasing with the discharge rate however, from a certain discharge rate the air will be sucked in. At first this is by large plugs of air, but when the water level rises they become bubbles decreasing in size with the water level. At a further increase of the water level the number of bubbles will decrease. The air being sucked in will collect underneath the disc of the air baffle from where it will be sucked in to the pipe system.

The collision of water on the edge of the disc and fins of the air baffle will lead to reflection waves. This is seen as an interference pattern of waves around the roof outlet, which becomes more significant at higher discharge rates.

The above phenomena are illustrated in the illustration below (illustration 7).

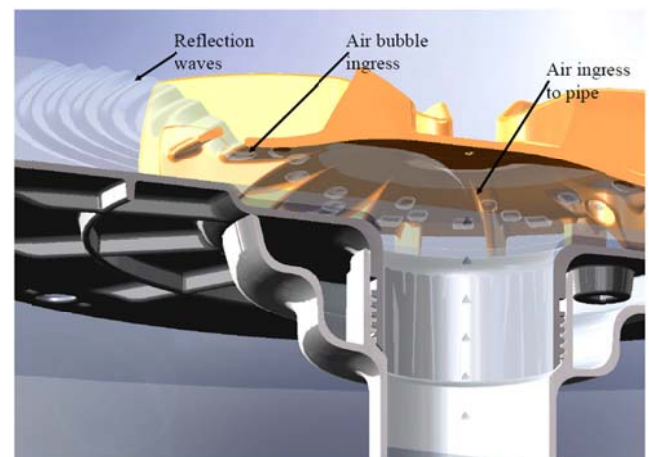


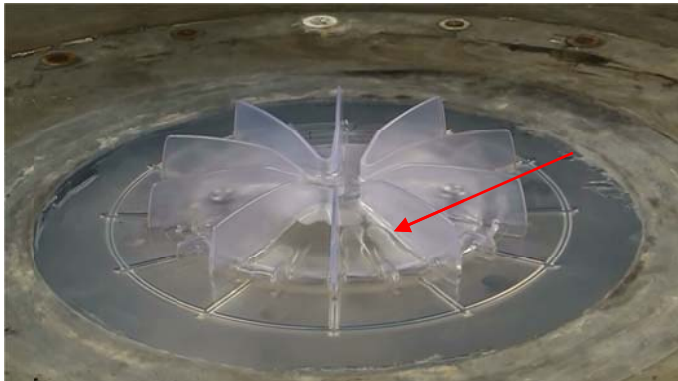
Illustration 7. Flow phenomena at roof outlet

As long as the water level is below the lower edge of the disc the air will be dragged in with the water as in a conventional system, the only influence of the air baffle being the prevention of a large vortex by the fin shaped ribs on which the baffle stands.

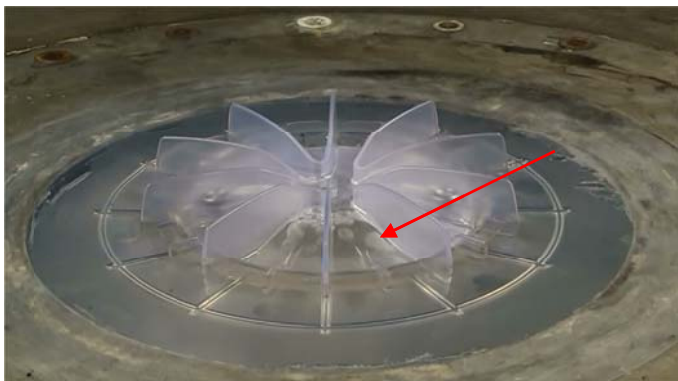
When the water level reaches the edge of the disc the air can not freely enter the system anymore but has to be sucked in by the under pressure generated by the water flow. At a low discharge rate the flow velocity is too low to drag in air, but when the water velocity increases large plugs of air manage to pass underneath the disc (illustration 8a). Initially the water is only occasionally capable of closing the gap for air to enter underneath the disc.

When the water level increases the plugs get shorter until bubbles remain (illustration 8b). The air has to overcome an increasing resistance by the water to find

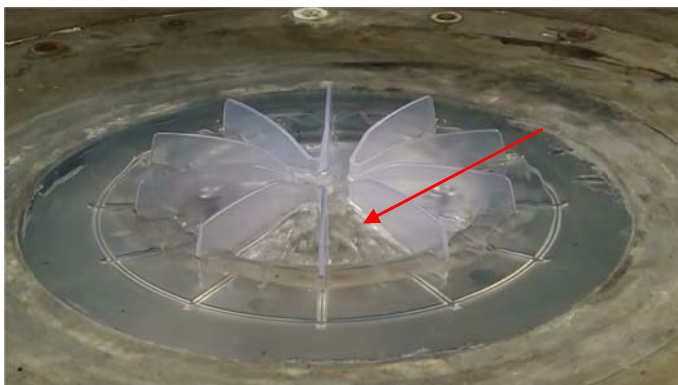
its way in when the water takes in more and more space above the air baffle.
When the discharge rate increases further the size of the bubbles decreases while the amount of bubbles increases (illustration 8c).



(a) large plugs of air just after reaching closure of water surface at the disc of the air baffle



(b) large air bubbles due to higher water level breaking up the plugs



(c) small bubbles at increased water level, but well before siphonic flow, inducing a high noise level

Illustration 8. Air ingress underneath air baffle (transparent)

When the water level rises further the frequency of the bubbles diminishes until the air is no longer capable of getting underneath the disc (the air is no longer capable of breaking the water surface to find its way in while the under pressure at the water surface

diminishes as the water level rises above the air baffle disc) and full bore flow is a fact.

When the flow has become fully siphonic a wave train is seen at the water surface around the air baffle every 0.75 s (thus at a frequency of 1.333 Hz). It looks like the roof outlet is pumping out water at this frequency producing a wave train with every pump stroke. In reality the water intake will be restricted every 0.75 s, probably because of a pressure wave traveling upstream from the exit.

At full siphonic flow the Ø75 roof outlet (with butt welded pipes) transports approximately 16.5 l/s, which converts to a mean velocity of 4.4 m/s in the pipe.

Since the pipe system is 4.2 m (total fall height) + 1.5 m (length of horizontal collector pipe) = 5.7 m long and the wave frequency is 1.333 Hz the speed at which the wave travels up and down the system is $5.7 * 2 * 1.333 = 15.2$ m/s, which is approximately 3.5 times the velocity through the pipe.

Indeed the exit flow is not a straight jet, it wobbles from left to right, although the frequency reported above can not be confirmed. The swinging motion appears to occur at a frequency of 8 Hz (=6*1.333 Hz)! It is not clear how to explain the factor of 6 between the wobbling of the exit flow and the wave frequency at the roof outlet.

4.4 Noise levels

Along with the break up in smaller plugs and bubbles the noise production rises as the noise is a result of the opening and closing of the water surface on the edge of the disc, which occurs more frequently when bubbles are dragged in at a high frequency.

When the frequency of the bubbles diminishes so does the noise production (because of the fewer opening and closing incidents of the water surface on the edge of the disc, see illustration 9 below).

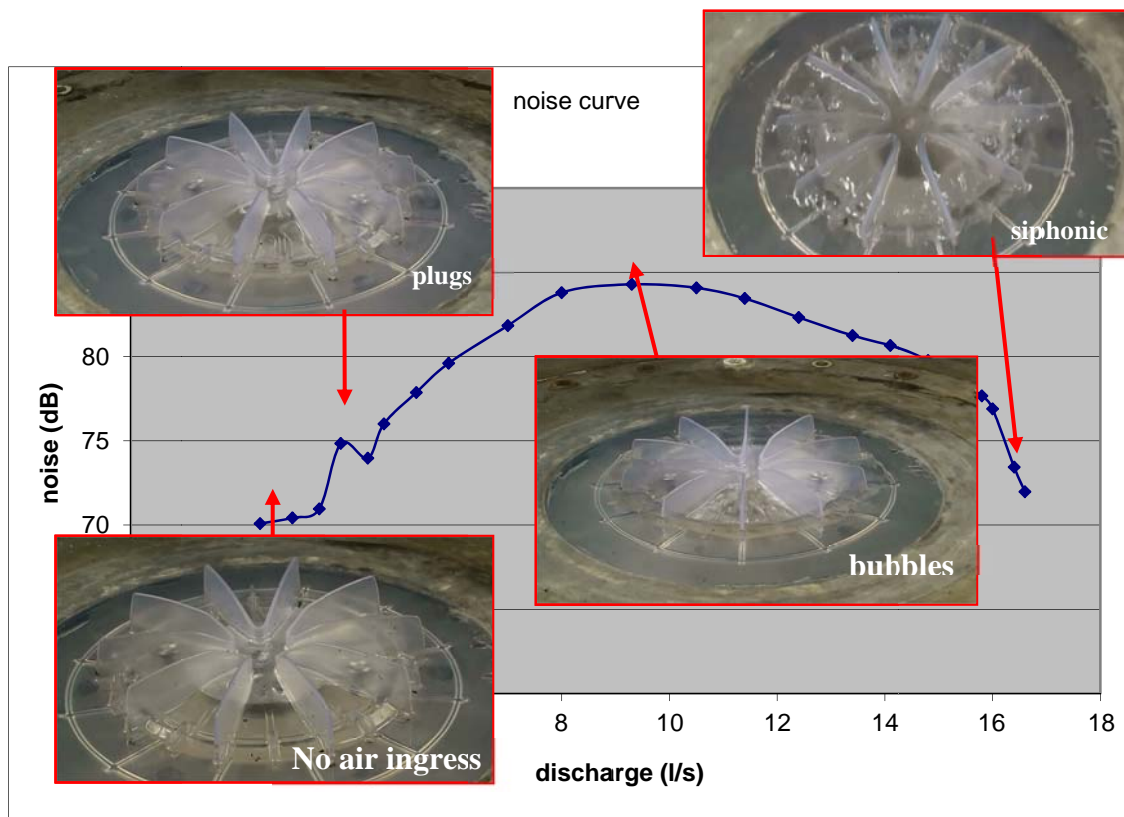


Illustration 9. Typical noise curve of siphonic roof outlet

5. Conclusions

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