Technical paper

What happens at the base of the stack?
The hydraulic jump theoretically explained

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Abstract

At the base of the soil and waste drainage stack the flow is diverted from vertical to horizontal. In the horizontal pipe the flow will decelerate leading to a hydraulic jump shortly after the change of direction. The hydraulic jump can result in a closure of the pipe diameter that will prevent air from traveling freely through the system to ventilate it and can result in pressure spikes endangering the integrity of the system. In this paper a theoretical approach for estimating the hydraulic jump has been laid out.

Context of this paper

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Research	Relevance	Design	Solutions	Materials	Installation	Terminology	Standards

Introduction

Water is accelerated through a soil and waste stack by gravity. In case of the annular flow pattern that must be maintained to keep the system ventilated the wall friction will counteract this acceleration to find an equilibrium. This balance will be disturbed at the bottom of the stack when the flow is redirected from vertical to horizontal. In the horizontal pipe gravity is no longer a driving force and the flow will decelerate by the only force acting upon it, the wall friction. This will result in a hydraulic jump. In this article we will describe the hydraulic jump and develop a method for estimating the hydraulic jump in a circular pipe system.

Theoretical background

In a stationary situation however the flow rate will be equal all through the pipe and the conservation of mass will prescribe that in case of a lower velocity of the flow it will have to occupy a larger cross sectional area:

$$A_1 \cdot v_1 = A_2 \cdot v_2$$

For a rectangular cross section that will not change width this leads to the two dimensional equation:

$$h_1 \cdot v_1 = h_2 \cdot v_2$$

For a circular cross section it can be described in terms of the filling grade of the pipe:

$$x_1 \cdot v_1 = x_2 \cdot v_2$$

Furthermore the momentum of the flow will have to be conserved. For the two dimensional situation the conservation of momentum is described by :

$$h_1 \cdot {v_1}^2 + \frac{g \cdot h_1^2}{2} = h_2 \cdot {v_2}^2 + \frac{g \cdot h_2^2}{2}$$

Unfortunately the momentum equation for the circular cross section gets very complicated.

Reformulating the momentum equation for the two dimensional cross section using the equation for mass conservation leads to:

$$h_1 \cdot \frac{{v_1}^2}{g} - h_2 \cdot \frac{h_1^2}{h_2^2}\frac{{v_1}^2}{g} = \frac{h_2^2}{2} - \frac{h_1^2}{2}$$

$${h_1}^2\left[1 - \frac{h_1}{h_2}\right]\frac{{v_1}^2}{g \cdot h_1} = \frac{h_2^2}{2} - \frac{h_1^2}{2}$$

$$\left[1 - \frac{h_1}{h_2}\right]\frac{{v_1}^2}{g \cdot h_1} = \frac{1}{2}\left[\frac{h_2^2}{h_1^2} - 1\right]$$

With: $x = \frac{h_2}{h_1}$ and $Fr = \frac{v_1}{\sqrt{g h_1}}$

$$\left[\frac{x-1}{x}\right] Fr^2 = \frac{1}{2}\left[x^2 - 1\right]$$

$$\frac{1}{2} x[x+1] - Fr^2 = 0$$

The only realistic solution for this quadratic equation is:

$$x = \frac{1}{2}\left[\sqrt{1 + 8Fr^2} - 1\right]$$

S.A. Ead and H.K. Ghamry have experimentally determined the values for x versus Froude number for circular conduits. The values for Circular (SG=0.00) apply for a soil and waste drainage system.

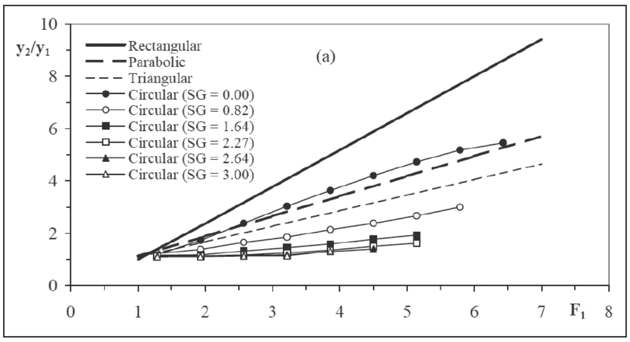

Figure 1.
X vs Froude number for circular pipes

These values can be used to estimate the height of the hydraulic jump in a soil and waste drainage system where the Froude number can be estimated by using the velocity calculated for annular flow as presented in the article "What flow rates can be handled by Stack-aerator Soil and Waste systems?" and determining the water height at the start of the jump using the profile of stratified flow having the same filling grade as the annular flow in the stack.

Estimations

The values for Circular (SG=0.00) presented in figure 1 have been curve fitted by a quadratic polynomial for predicting the height of the hydraulic jump for the Froude number using the velocity of the annular flow theory and water height obtained using the filling grade of the annular flow theory for stratified flow. It has been calculated what will be the height of the hydraulic jump at the maximum annular flow through a system with a Ø110 pipe diameter, at the maximum flow rate of a stack-aerator system and what flow rate would just lead to a closure of the pipe diameter. Additionally the flow rate that would lead to a filling grade of 75% [h/D=0,70] has been determined.

Ø110	**Flow rate [l/s]**	**Height of hydraulic jump [mm]**
Max annular flow rate	10,665	193,9
Max flow rate	7,6	168,4
Closure	2,62	101,6
h/D = 0,70	1,33	71,3

Table 1.

The table shows that the hydraulic jump will close off the entire pipe diameter for flow rates exceeding 2,6 l/s. For a reasonable ventilation of the horizontal pipe [h/D = 0.70] the maximum flow rate will be only 1,33 l/s. This means that the pressure relief line is an absolute necessity for keeping the system ventilated.

It should however be noted that the European lay-out of the base of the stack using two 45 degree elbows will lead to other results since the hydraulic jump is spread out over the two elbows instead of one 90 degree bend and thus the assumptions used might not be valid.

Conclusion

A method for estimating the hydraulic jump at the base of the stack has been developed based on experiments performed by Ead and Ghamry on hydraulic jumps in circular conduits using input values from annular flow theory.

The results gained from this method shows that for a Ø 110 stack-aerator system the hydraulic jump for a flow above 2.6 l/s will close off the entire pipe diameter and thus a pressure relief line is an absolute necessity according to this method for estimating the hydraulic jump.

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