DESIGN CRITERIA FOR OVERFILL DRAINAGE LINES IN CLOSED TANKS

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INTRODUCTION

A tank overfill occurs when the liquid stored in a tank surpasses its capacity, leading to a spill. This can happen under various scenarios, such as during filling, due to operator mistakes, equipment malfunctions, etc. Tank overfills can cause environmental harm and pose safety risks when the liquid stored is hazardous. Besides, it can lead to financial losses, as well as damage the tank and related equipment.

Storage tanks must be equipped with overfill lines to allow the contained fluid to be safely discharged in a controlled manner. Overfill lines must be connected to the tank near the top, below the feeding line filling. It is crucial for an overflow line to be designed to be self-venting. Otherwise, an overflow situation may easily cause the tank failing due to vacuum.

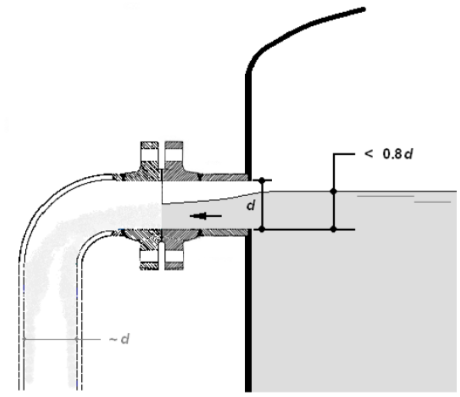


Figure 1. Scheme of overfill line in tank [1]

Overfill lines in tanks are usually vertical pipes in which the liquid flows downwards by the action of gravity (see Figure 1). They mean free-surface flows where the flow of liquid does not completely fill the pipe section, coexisting therefore with an air phase. When gas and liquid flow simultaneously in a pipe or conduit, several flow regimes can result depending on the pipe geometry, fluid properties, volume fractions and velocities of each phase.[2] In vertical pipes, the most commonly described flow regimes are bubble, slug, churn and annular flows, as depicted in Figure 2.

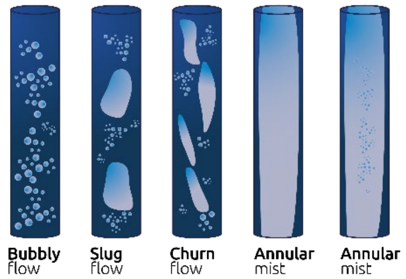


Figure 2. Characteristic flow patterns in vertical pipes [3]

In bubble flow the liquid flows downward, forming the continuous phase, while the gas is dispersed in the liquid as individual bubbles. These bubbles are distributed throughout the entire cross-section of the pipe, increasing in number, size, and speed as the gas flow increases.

In slug flow, the bubbles merge to form elongated gas plugs with a parabolic leading edge. The liquid descends along the film surrounding these gas plugs. When the gas superficial velocity is high, the descending liquid around the gas plugs nearly stops, causing instability in these gas plugs and their subsequent rupture. The liquid begins to flow turbulently and oscillatory in a churn flow pattern. Both phases flow as a turbulent mixture, with structural elements in a continuous process of collapse and reformation. This phenomenon occurs over a wide range of gas superficial velocities.

In annular flow or falling film flow, the liquid flows downward as a film along the inner walls of the pipe, forming a ring, with the gas flows through the center. The gas usually drags a portion of the liquid in the form of droplets, which flow at the gas velocity. Finally, in mist flow the liquid flows as fine droplets dispersed in the gas, which constitutes the continuous phase.

To prevent air locking in vertical overfill drain lines, the liquid velocity must be kept low enough to allow air to vent back into the tank. The only reliable method to ensure free-surface flow is to make the pipe diameter large enough to prevent the formation of unusual flow patterns and to achieve annular flow.[4]

EXPERIMENTAL METHOD

According to Hills' research [5] gravity flow in self-venting drainages must meet two simultaneous conditions to ensure side outlet flow without siphon effect, or any undesired flow pattern different from annular pattern. This involves a minimum diameter at the entrance boundary to the outlet and a maximum Froude number (Equation 1):

$$ID > \left(\frac{4 \cdot Q}{0.3 \cdot \pi \sqrt{g}}\right)^{0.4} \qquad \text{(Eq. 1)}$$

$$Fr < 0.3$$

where:

D is the inner diameter of the pipe in m
Q is the flow of liquid in m^3/s
g is the gravity in m^2/s

The above inequalities ensure that the depth of flow in the pipe will be less than half full at the entrance to the outlet. As shown in Figure 1, to insure self-vented gravity flow, a critical far field (away from the outlet) static fluid height less than 0.8d must be maintained.[1]

The Froude number is dimensionless number used to indicate the influence of gravity on fluid motion. It is defined as the ratio of the inertia force acting on a fluid element to the weight of that fluid element and can be calculated with Equation 2.

$$Fr = \frac{u}{\sqrt{g \cdot ID}} \qquad \text{(Eq. 2)}$$

where:

u is the flow velocity in m/s

Besides, keeping Fr numbers below 0.3 is a widely accepted criterium in the scientific community to achieve a self-venting line in which the liquid can be easily drain from the tank.

CASE OF STUDY

In this paper, we want to design an overfill pipe that can drain the maximum flow of water fed to the tank depicted in Figure 3. This tank has 1200 L of storage capacity and can be continuously fed with up to 9 m^3/h of water. Besides, the piping class specification sets that pipelines must be built in NPS from 1 to 6 in, always with schedule 10s.

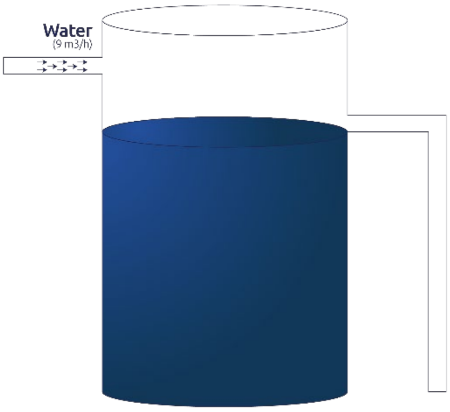
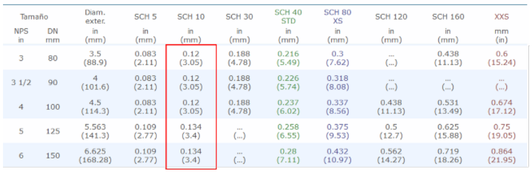


Figure 3. Scheme of case of study

Setting 9 m^3/h of water as the maximum flow to be drained, the minimum inner diameter for the drainage pipe can be calculated with Equation 1.

$$ID > \left(\frac{4 \cdot 0.0025}{0.3 \cdot \pi\sqrt{9.81}}\right)^{0.4} = \mathbf{0.103\ m}$$

Now, a pipe nominal diameter must be selected from the available sizes in ASME B36.10M standard. As shown in Figure 4, a pipe diameter of **NPS 4 in and Sch. 10S** complies with the requirement, since its inner diameter would be of 0.108 m, and therefore higher than the 0.103 m obtained from the calculation.



Tamaño		Diam. exter.	SCH 5	SCH 10	SCH 30	SCH 40 STD	SCH 80 XS	SCH 120	SCH 160	XXS
NPS in	DN mm	in (mm)	in (mm)	in (mm)	in (mm)	in (mm)	in (mm)	in (mm)	in (mm)	mm (in)
3	80	3.5 (88.9)	0.083 (2.11)	0.12 (3.05)	0.188 (4.78)	0.216 (5.49)	0.3 (7.62)	... (...)	0.438 (11.13)	0.6 (15.24)
3 1/2	90	4 (101.6)	0.083 (2.11)	0.12 (3.05)	0.188 (4.78)	0.226 (5.74)	0.318 (8.08)	... (...)	... (...)	... (...)
4	100	4.5 (114.3)	0.083 (2.11)	0.12 (3.05)	0.188 (4.78)	0.237 (6.02)	0.337 (8.56)	0.438 (11.13)	0.531 (13.49)	0.674 (17.12)
5	125	5.563 (141.3)	0.109 (2.77)	0.134 (3.4)	... (...)	0.258 (6.55)	0.375 (9.53)	0.5 (12.7)	0.625 (15.88)	0.75 (19.05)
6	150	6.625 (168.28)	0.109 (2.77)	0.134 (3.4)	... (...)	0.28 (7.11)	0.432 (10.97)	0.562 (14.27)	0.719 (18.26)	0.864 (21.95)

Figure 4. Extract of ASME B36.10M standard with pipe diameters[6]

Finally, the Froude number is calculated with Equation 2 to check that this condition is also fulfilled.

$$Fr = \frac{u}{\sqrt{g \cdot ID}} = \frac{\frac{4 \cdot Q}{\pi \cdot ID^2}}{\sqrt{g \cdot ID}}$$

$$Fr = \frac{\frac{4 \cdot 0.0025}{\pi \cdot 0.108^2}}{\sqrt{g \cdot 0.108}} = \mathbf{0.27 < 0.3}$$

In conclusion, a pipe diameter of **NPS 4 (sch. 10S)** is the best choice for the design of this drainage system, because it will allow to achieve a self-venting line when water overfills the tank.

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