Investigation of the effect of swept entry configuration on the air entrainment and self-siphoning behaviour in gravity drainage systems

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Abstract

In this study, a typical wastewater drainage system composed of different swept entry configurations are systematically investigated. A high tower test stand, which allows the installation of a 24 m high stack combined with a 3 m side branch is available to conduct the tests. The drainage through the side branch is simulated by pumping water into a flushing appliance which then flows into the lateral branch pipe in order to create the flow conditions representing the actual drainage system installed in a building. Here, it is primarily reported on the seal loss as affected by the variation of branch pipe offset and the ratio of flow rates in these two pipes. The ratio of branch pipe size to main stack size is also considered as a relevant parameter to effect the seal loss behaviour.

The results are presented in the form of spatial seal loss distributions on the stack with and without a side branch connection. In addition to the experimental analysis, various configurations of the tested system are simulated utilizing a computational fluid dynamic (CFD) method in this study. The use of this method, on one hand displays the important characteristics of the drainage flow visually; on the other hand it provides extensive flow data including flow velocities and transient pressures.

Keywords

swept entry configuration; transient drainage flow; self-siphoning; seal loss

1 Introduction

Layout and dimensioning of gravity drainage systems are well described by European standards [1]. According to these standards the maximum discharge rate of the stack depends on the design of the junction between branch and stack pipe [1]. For angled flow into the stack (swept entry) the standards allow a higher flow rate than for a straight (perpendicular) entry. This aspect has been discussed extensively in the
literature [3,7] and this solution has been widely adopted by the sanitary equipment industry. Despite its widely spread application of this solution in the industry, the standards still don’t describe a particular configuration for the swept entry fitting, and therefore there is an ongoing dispute on the definition of the ideal junction design. Moreover, previous investigations have shown that the junction design has a substantial effect on the self-siphoning behavior in the branch pipe [2,4,8].

This study focuses on enlightening the reasons behind the effect of the most relevant parameters on the functioning of the traps and increasing or reducing the seal loss accordingly. It is expected that a detailed examination of flow related activities especially near the side branch junction can help to define an optimal configuration for the fitting geometry. It is also expected that a systematic collection of experimental data in this study can provide a basis for the development of a reasonable methodology to assess swept entry drainage pipe fittings in the future.

Computational fluid dynamics (CFD) has emerge as one of the powerful methods to be used to predict and analyse flow related problems in sanitary applications. The same technique is used in this study to simulate the flow in a junction model representing the side branch entry configuration, thereby exploiting the characteristics of flow activities which are closely related to trap seal loss.

2 Experimental and Computational Techniques

2.1 Experimental set-up

The tests have been conducted in the high tower test stand of Geberit Labs, which allows the installation of a 24 m high 8 story stack combined with a 3 m long side branch as the discharge pipe. The distance between the stories is 2.65m except the bottom and the top stories where the height increases to 3.31 and 3.35m, respectively. The main stack is made of a 110 mm diameter PE-pipe. Either a 110 mm (D110) or a 90 mm (D90) PE-pipe has been used as the side branch in order to be able to observe the effect of branch pipe size on the seal loss. A sketch displaying the overall configuration of the piping system in the test tower is given in Figure 1(a).

The water is supplied to the stack at two locations as indicated in this figure. The main supply is from the straight entry on the 7th floor. The second supply is from the side branch located on the 4th floor. The water supply from both the main and the side branch entries is provided by means of a feed pump. Two valves mounted on the two feed pipes separating from the pump discharge line regulate the flow rate required for each entry. On the branch pipe side, the water is fed first into a cistern from which it flows freely into the branch pipe in order to simulate a flushing process. By this way it has been possible to create the flow conditions, which represent an actual drainage system in a building. During the tests both the discharge rate in the main stack and the branch pipe has been adjusted so that the total discharge from the stack is kept at a constant level of 5.2 lt/s throughout the tests. The discharge rate in the main stack is adjusted to 2.7, 3.6, 4.4 and 5.2 lt/s, whereas the discharge in the side branch is varied in four steps to 2.5, 1.6, 0.8 and 0.0 lt/s, respectively depending on the test case. The flow rates were
monitored continuously during the tests by two flow meters mounted on the feed lines.

The investigation of the influence of swept entry configuration on seal loss has been monitored continuously during the tests by two flow meters mounted on the feed lines.

Figure 1 - Sketches illustrating (a) overall configuration of the test stack with discharge locations and measurement floors; (b) a general view of branch pipe inlet and (c) two special branch pipe inlet configurations, tested in this study.

The maximum discharges 2.5 and 5.2 l/s correspond to the maximum allowable values according to the requirements of the related standards [1] for the selected side branch and the main stack pipes, respectively.

The investigation of the influence of swept entry configuration on seal loss has been carried out by implementing a variety of commonly used entry fittings on the branch

Figure 2 – A typical trap connection used to measure the seal loss distribution along the main discharge stack.
pipe at the 4th floor. Most of the tests have been carried out with 45° angled entry type of joint, a sketch of which has been given in Figure 1(b). Some of the relevant geometrical parameters are also indicated in this figure. The geometry of the standard 45° joint has been changed by varying either the branch pipe diameter, $D_b$, or the branch pipe offset, $H_b$. In addition to the 45° joint, two special entry configurations, a straight entry and a curved swept entry, have been used for comparison. The sketches of these two special cases are illustrated in Figure 1(c).

2.2 Measurement technique

The measurement of seal loss has been accomplished utilizing a series of instrumented traps mounted on the main stack at 7 of the test tower floors. The traps at floors 1-3 and 5-6 have been connected directly to the stack through an adaptor piece which is 0.3m long as shown in Figure 2. The trap mounted on the side branch is 1 m apart from the stack. A second trap is added to branch located 1 m away from the first one in order to monitor the transient activities inside the branch itself. The free end of each trap is closed with a cap, which allows mounting an ultrasound distance meter, and a water fill pipe and possesses an air vent. The traps are filled up to the rim with water before each test under standstill conditions. The pump is run up to the predetermined flow rate gradually and slowly enough so that an excessive seal loss due to start-up transients is prevented. Duration of the tests has been set to 3 minutes for each case, which is followed by a 1 minute settling period for the trap water. By this method it is possible to determine the maximum seal loss level reached during the tests. The trap water level as detected by the ultrasound meter on each trap has been recorded on a portable computer at the end of this period.

3 Results

The seal water loss is used as a means to determine the severity of the dynamic pressure pulsations in the drainage piping system. This method is used widely in the literature [6, 7] for such purposes because of its simplicity to install and being a direct instrument indicating the level of trap water suction. The seal water height, $h_{sw}$, given in this study, can easily be converted into maximum suction pressure level when it is required.

3.1 Characteristics of trap suction in a single stack discharge without a side branch

A series of measurements has been carried out in order to determine the distribution of seal water loss along the discharge stack which provides a basis for comparison with the succeeding measurements in the following sections. The seal loss distributions for a flow rate range of $2.7 < Q_m < 5.2$ lt/s are given in Figure 3. As examined in the distributions of this figure a local seal loss maxima is reached immediately after the discharge inlet near the 6th floor, which gradually decreases in the downstream to about 30 percent of the maximum level. The same set of data are normalized with respect to the local maxima and plotted in Figure 3(b). All the data are very well correlated and collapse on a characteristic distribution as it is clearly observed in this figure. This characteristic distribution is typical for similar type of discharge stacks which have been reported many times in the literature [2,5].
Figure 3 – The reference seal loss measurements in a discharge stack without a side branch. (a) Distributions of absolute seal loss level for 4 different discharges and (b) seal loss distribution as normalized by the maximum level of each case.

Figure 4 – Variation of seal loss in the reference discharge stack without a side branch as a function of flow rate.

The characteristics of seal loss has been further displayed in Figure 4 where the variation of normalized seal loss measured at all floors are given as a function of flow rate. The solid curve given on the same figure represents the best fit to the data, whereas the dotted line has been determined by applying the empirical methodology presented by Lu et al. [6]. The equation describing this line is given as:

\[
\frac{h_{sw}}{h_{max}} = 0.03568 \cdot Q_m^2 + 0.00659 \cdot Q_m
\]

(1)

and has the same form as that of Lu et al. which is given to calculate the peak negative air pressure, \(p_{na}\), occurring in a single stack discharge pipe. Although Lu et al. [5,6] have used this approach to predict \(p_{na}\), it should be recalled that seal water suction from
the traps connected on such a system is directly proportional to \( p_{\text{na}} \). Therefore, the application of the same methodology for seal loss prediction in this study is clearly justified. In fact, it is examined in Figure 4 that Equation (1) represents the measured data quite well. The analysis of the results in this section proves that both the experimental set-up and the measurement method adopted to be utilized in this study are suitable for a detailed and an accurate examination of the problems investigated.

### 3.2 Trap suction on a stack combined with standard side branch junctions

The characteristics of seal water suction from the traps connected on a single stack discharge pipe combined with a side branch having three different types of commonly used standard junction geometries, a straight entry, a swept entry and a 45° angled entry with \( H_b/D_b=1 \) (see Figure 1), have been examined as the first case of this study. The seal loss distribution along the stack in the vicinity of these junction elements are given in Figure 5 for two different discharge combinations of \( Q_m/Q_b=2.7/2.5 \) and \( 4.4/0.8 \) lt/s, in the main stack and in the side branch, respectively. Here it should be recalled that the sum of the discharges of each combination is 5.2 lt/s which is the maximum allowable level for the main stack size used. The third curve resembled by open symbols added to all three plots belongs to the reference case of discharge stack without the side branch for a discharge rate of 4.4 lt/s.

![Figure 5 – Distribution of seal loss along the stack with (a) a straight entry, (b) a swept entry and (c) 45° angled entry junction for \( Q_m=2.7 \) and 4.4 lt/s in comparison to the reference case without a side branch under the same flow conditions.](image)

In all three cases, the seal loss distribution shows similar characteristics from the main discharge at the 7\(^{\text{th}}\) floor up to the side branch discharge at the 4\(^{\text{th}}\) floor. Especially the data belonging to the flow rate of 4.4 lt/s follow the same curve at the upstream of this junction. A significant deviation from this distribution is first examined at the downstream of this junction where an appreciable increase is observed in the seal loss. This increase in the seal loss can be attributed partly to the increase in the total discharge as a result of merging of the flow from the side branch into the main stack discharge, and partly to the strong changes in the flow activities because of the
differences in the junction geometry. The effect of the junction geometry is examined best by comparing the straight and swept entry cases of figures 5(a) and 5(b) with the 45° entry configuration given in Figure 5(c). It is interesting to note that the most significant difference occurs when the proportion of the flow from the side branch approaches to that of the main stack, i.e. $Q_m/Q_b \sim 1$.

### 3.3 The effect of side branch offset on the trap suction characteristics

The effect of junction geometry on the seal loss is examined further by changing the offset of a 45° angled entry on the side branch as sketched above in Figure 1(c). The investigation of this aspect of entry configuration is particularly important in this study since a binding definition of the junction is not provided in the standards, therefore implementing a fitting with an optimal geometry depends solely on the experience.

![Figure 6 - Seal loss distribution along the stack with a 45° angled junction having an offset of (a) $H_b/D_b=1$, (b) $H_b/D_b=1.3$ (c) $H_b/D_b=3.12$ for $Q_m=2.7$ and 4.4 l/s as compared to the ref. case without a side branch under the same flow conditions.](image)

The seal loss distributions for three different offset ratios from $H_b/D_b=1$ to 3.12 are displayed in Figure 6. Although a behavior similar to that discussed in the previous section is observed at the upstream of the side branch junction, a significant difference is examined in comparing the cases corresponding to the lower discharge range of 2.7/2.5 l/s at the downstream of the junction. It is important to mention here that the seal loss tends to increase gradually in this zone in the offset range of $H_b/D_b<1.5$ whereas it is reduced to lower levels thereafter in the range $H_b/D_b>1.5$. This behavior is best displayed in Figure 7 where the seal loss is presented as a function of branch pipe offset in the range of $0 < H_b/D_b < 3.12$ for the flow rate ratio of $Q_m/Q_b = 2.7/2.5$ l/s. The data in this figure indicates that in the upstream zone (5th $F$) the dependency of the seal loss on the offset ratio disappears. However, in the downstream zone (3rd $F$ and 4th $F$), a relatively strong dependency on the offset ratio exists. In this zone a significant increase occurs in the seal loss as the offset is increased to about 1.5$D_b$. At the 3rd floor just behind the junction the seal loss tends to increase further as the offset is reduced to
a level below $H_b/D_b < 1$. The data points corresponding to the two lowest offset ratios in this plot belongs to the straight and swept entry configurations where $H_b/D_b=0$ and $H_b/D_b = 0.2$, respectively.

On the other hand, the seal loss tends to decrease again as the offset ratio is increased over $H_b/D_b>1.5$ reaching to about the same level as that measured at the upstream floors. The appearance of such a critical offset range causing excess seal loss can be attributed to the strong changes in the flow activities developing near the junction. These issues will be further assessed in the following sections.

![Figure 7](image)

**Figure 7** – Seal loss measured at the 3rd, 4th and 5th floors as a function of side branch offset in the vicinity of flow condition $Q_m/Q_b = 2.7/2.5$.

3.3 Characteristics of flow activities in the stack near the side branch junction

The behaviour of flow activities which are directly related to the changes in the seal loss is investigated utilizing computational fluid dynamics (CFD) methods in his study. A piping model which covers the most relevant flow conditions has been used in the

![Figure 8](image)

**Figure 8** – Main flow activities in the stack with a $45^\circ$ angled junction having an offset of (a) $H_b/D_b = 1.3$ and (b) $H_b/D_b = 3.12$ for $Q_m/Q_b = 2.7/2.5$. 
simulations. This model allows a conduit flow inlet at the main stack border whereas it possesses a full flow entry at the side branch border. A set of simulation results is presented in Figure 8 corresponding to the flow condition of $Q_m/Q_b = 2.7/2.5$. The coloring of the flowing water corresponds to the speed of the flow in the piping. In Figure 8, the side view of the steady state flow at the mid-cross-section of the side branch junction for an 45° angled entry having an offset ratio of $H_b/D_b=1.3$ and 3.12 are displayed. Both pictures indicate that the flow entering the side branch settles first in the horizontal part of the branch and then it is accelerated into the angled portion from which it enters into the junction and merges with the conduit flow. Due to the combined effect of relatively strong acceleration and the 45° slope of the junction pipe, the flow is separated from the turning corner of the side branch as it flows over the corner. Although the separation zone is clearly apparent in both cases given in Figure 8, a slightly larger zone which is extending into the junction is observed in the picture corresponding to $H_b/D_b=1.3$. The reattachment of the separation zone is hardly detected in this case meaning that the unsteady separated flow activities are directly coupled with the main stack flow near the junction region. The occurrence of such a coupling enhances the unsteady pressure fluctuations and result in higher seal losses in this particular case.

A direct mixing of the separation zone with the junction flow is not observed in the simulation picture corresponding to the offset case of $H_b/D_b=3.12$ in Figure 8(b). The relatively long junction pipe causes the reattachment of the separated flow to the pipe wall in this case and allows the flow to settle back to a relatively stationary pipe flow. The lack of a direct coupling of the separation zone with the main stack flow results in occurrence of less unsteady flow activities and hence weaker pressure pulsations resulting in lower seal losses. This finding is in comply with the previous examinations presented in section 3.2.

4. Conclusions

This paper investigates the effect of the most relevant geometrical and flow related parameters on seal loss from traps implemented on a single stack discharge piping containing a side branch connection. It has been shown that the experimental methodology utilized in this study in order to collect data and analyse the results conforms very well with those provided in the literature. This study particularly attempts to examine the effect of side branch offset and main stack to side branch flow ratio on the seal loss. A dependency of seal loss on these parameters can be clearly displayed through the results of the experiments carried out in this study.

The investigation of these parameters is very important since they are not included extensively under the regulating standards. It is assumed that the results obtained in this study can be used in connection with those of similar studies in the literature as a reference to define the geometrical constraints and flow ranges for optimal junction configuration which are not provided in the standards.

The experimental measurements carried out in this study can be supported by the results of computational fluid dynamic simulations which is capable of enlightening many features of complicated flow activities related to these measurements.
5 References


6 Presentation of Authors

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