HOW TO ENHANCE UNIFORM DISTRIBUTION WITHIN A PERFORATED PIPE: A MATTER OF SWEET BALANCE

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Abstract

It is acknowledged and recognized that even distribution of wastewater is key to optimizing the use of the dispersal area and consequently improving the quality of treatment provided. The most prevalent method of wastewater distribution onto conventional sand or soil-based infiltration systems consists of perforated pipes with clean crushed stone. Of course, the quality of distribution will be impacted by the way the wastewater is conveyed to the perforated pipes, whether it is by gravity, dosed, or using low-pressure distribution, the latter being recognized as being the most efficient. However, it has been observed and documented that the quality of distribution achieved with perforated pipes, especially when fed by gravity, is far from uniform.

In an effort to enhance the quality of wastewater distribution for one of its systems, Premier Tech Water and Environment (PTWE) conducted a comparative analysis of the distribution quality achieved using different patterns of perforations along a lateral. Different patterns of perforation density, shape, size, and location were assessed against conventional perforated pipes benchmark. The trials were conducted in a controlled environment with clear water along a run simulating a 20-ft long trench. The tests were carried out using a number of different feeding modes and dosing regimens. Reducing the number of orifices and their size have been identified as 2 important optimization factors, whereas their geometry and location also showed a non-negligible impact on water distribution quality. Furthermore, it was observed that the volume of the dose also significantly improves the distribution compared with the gravity-fed alternative.

Introduction

Most conventional approaches, such as leach fields and sand filter beds, as well as some alternative technologies, combining treatment and dispersal, developed for decentralized domestic wastewater treatment, rely on the biofiltration principle. For conventional systems, the primary sizing criterion typically relates to the hydraulic capacity of the receiving soils.
It is generally referenced by the long-term acceptance rate (LTAR) that corresponds to the volume of water applied per unit of surface area of the receiving site (gal/ft².d). The LTAR is determined based on factors such as the receiving soil texture, structure, and permeability, where lower soil permeability necessitates a larger system. Regarding sand filter beds and technologies that combine treatment and dispersal, the sizing is generally dictated by the hydraulic loading rate of wastewater applied to either the surface of filtering material, the length or surface of treatment/dispersal components. The extent of treatment accomplished is directly related to this

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hydraulic loading rate. However, in addition to water treatment considerations, due attention shall be given, for final dispersal of treated effluent by infiltration, to the soil permeability. Here again, lower soil permeability necessitates larger systems. In all these cases, whether it involves a conventional system or a technology that combines treatment and dispersal, the wastewater is conveyed and distributed over the required surface and then flows by gravity. When soil, sand or other filtering material is involved, it moves by capillary action through the network of pores within the bed. This movement of water, from the surface to the bottom of the filtering material (FM) of the system, naturally entrains the air necessary for the aerobic biological activity, thereby aiding in the removal of pollutants.

The feeding regimen and water distribution across the surface significantly affect water and air flow within the FM and thereby influence the treatment level provided and the aging process of the filter bed and/or the absorption area. The more compact the filter, the greater the hydraulic loads applied, which amplifies the impact of an unbalanced distribution. It is, however, easier to provide good distribution on a smaller surface. At lower design loads, achieving an even distribution of the water across a larger surface of the filtration bed presents a significant challenge, thereby increasing the likelihood of overloading specific zones. This can result in suboptimal treatment performance and accelerated sludge accumulation within these areas (Converse, Anderson et al. 1974, Otis 1981, Hargett, Tyler et al. 1982, Bomblat, Wolf et al. 1994).

The most common method of wastewater distribution onto conventional sand or soil-based infiltration systems involves perforated pipes with clean crushed stone. The very low water velocity at the outlet of a septic tank results in water travelling only short distances in distribution pipes. Depending on the flow, water will most likely exit through the first draining holes encountered on its path(Mitchell 1982, Machmeier and Anderson 1987). However, as these holes get clogged with sludge and biomass accumulation, water's path will be redirected to farther distances along the pipe. Of course, the quality of distribution will be impacted by the method of conveying wastewater to the perforated pipes, whether it is by gravity, dosed, or using low-pressure distribution, with the latter being recognized as being the most efficient (Dubé and Barabé 1991). It has been observed and documented that the distribution using perforated pipes, especially when fed by gravity, is far from uniform (Otis, Converse et al. 1977, Mercier 2023).

There are different ways to enhance water distribution across these systems, most of which rely on increasing water velocity within the distribution pipes. The most efficient method used in the decentralized wastewater treatment industry is low-pressure distribution, where the water to be distributed is pumped into a network of small-diameter perforated conduits. This approach helps achieving a mostly uniform surface distribution while mitigating the negative impact of uneven levels of pipes on distribution(Converse, Anderson et al. 1974, Otis, Converse et al. 1977). Using a pump makes the installation suitable for different site topographies; this approach however generally increases the cost. A cheaper and more passive way to improve distribution is to use gravity dosing devices. These devices collect water in a retention reservoir until a mechanism (siphon, buoyant component, valve, tipping bucket) is triggered to permit water discharge, allowing for an on-demand dosing over the system. This method uses the potential energy of an accumulated waterhead to generate velocity, allowing the water to travel further down the distribution pipe(Falkowski and Converse 1987). The higher the waterhead and the larger the volume, the greater is the velocity. While the distribution quality of the low-pressure approach mostly relies on the pipes' loading by the pump, that of the gravity dosing continues to depend on the orifice pattern of the distribution conduits.

In North America, 3- or 4-in diameter pipes are typically used for this purpose, with paired ½-in diameter orifices oriented at 120º evenly spaced along the pipe's length, usually 4 orifices per linear foot (BNQ 3624-050/2015). These pipes also feature a few drainage holes at their centered bottom (1 per 5 ft). In Europe, 4-in diameter slotted pipes are common, with 3/16-in wide and approximately 3-in long slots evenly distributed along the pipe's length, ranging from 1 to 3 slots per linear foot (AFNOR 2013). Although these hole patterns are widely adopted and included within standards, making them accepted *de facto*, they may not be the optimal choice for achieving uniform water distribution over a large surface. This paper questions the current perforation patterns and proposes an alternative to improve distribution under gravity-fed conditions, gravity and dosed.

Materials and Methods

An experimental setup was constructed to characterize the distribution quality of different perforation patterns and feeding regimens (Fig. *1* & 2). The water collection setup comprised of a series of racks to support the tested conduit and maintain it in a level position. Beneath these, 2-ft long containers were arranged to collect the water coming out of the perforations at regular increments from the beginning of the line. Each experimental scenario involved of 20-ft perforated pipes or distribution conduits integrated to chambers (DCIC), which were either fed via a dosing box or a calibrated-flowrate hose (Fig. 1).

In order to evaluate the impact of the tested conditions in comparison to a reference, an initial trial was conducted (Test 1) using a standard 4-in perforated pipe, as defined per North American standards. Aside from the reference trial with the 4-in pipe, all other perforation patterns and geometries tested were done in DCIC, where the conduit is equivalent to a 4.5-in pipe, which was integrated to the top wall of a 4-ft long distribution chambers.

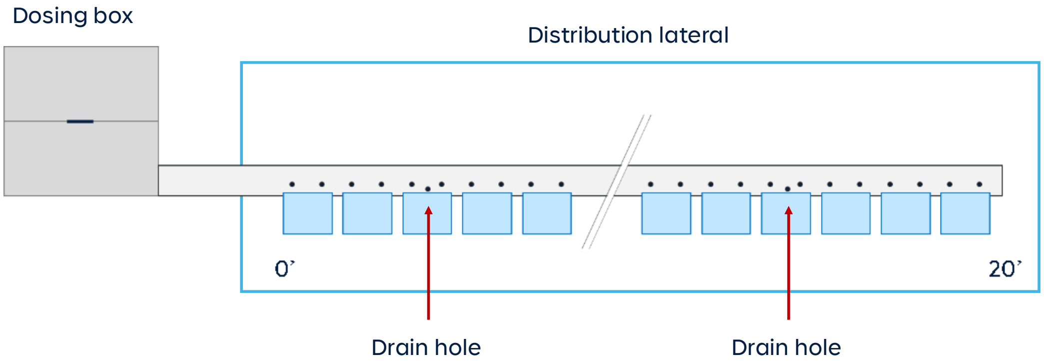

Fig. 1. Schematic representation of the experimental set-up

For dosed trials, 4-gal of clean water were flushed from a 1.1 ft²-bucket into a single-outlet dosing box connected to the tested setup through a 3-ft-long pipe (4-in diameter; 0.5%-sloped) This configuration corresponds to a linear hydraulic load (LHL) of 0.2 gal/ft of conduit.

For calibrated-flowrate trials, 4-gal of water were applied at a given flow rate to the same distribution box, using a timer, prior to freely flowing into the tested conduit. These experiments were conducted to assess the impact of selected patterns under a continuous feeding regimen on distribution quality.

Fig. 2. Schematic representation of tested variables in DCIC

All tests were conducted in duplicate, and the quality of distribution was ascertained by calculating the coefficient of variation (CV) of the water collected in the containers, based on the average of the two runs.

Results and Discussion

Impact of Perforation Pattern on Distribution Quality

Test 1 was conducted using a typical 4-in pipe as a reference, while all subsequent tests employed 4-ft-long distribution chambers featuring an integrated 4½-in equivalent distribution conduit (referred as DCIC). No drainage holes were drilled at the bottom of the DCIC, as the junctions between chambers are anticipated to serve this function. Considering that drain holes are prone to clogging rapidly under typical septic conditions, their long-term effectiveness may be questionable. Consequently, it was imperative to assess scenarios devoid these supplementary drainage holes; therefore, Test 2 mirrors Test 1, but without the drainage holes.

Table 1. Tested parameters during dosed trials and their impact on the distribution quality

Test	**Conduit type**	**Drainage hole** (⅜ in)	**Perforation density** (/ft)	**Perforation size (∅ or width)** (in)	**Perforation geometry**	**Free-flow channel width** (in)	**Distribution quality** (Coeff. Var.)
1	4-in pipe	Present	4	½	Hole	4	157%
2	DCIC	Absent	4	½	Hole	4	104%
3	DCIC	Absent	3	½	Hole	4	96%
4	DCIC	Absent	2	½	Hole	4	108%
5	DCIC	Absent	4	½	Hole	1	132%
6	DCIC	Absent	3	½	Hole	1	120%
7	DCIC	Absent	2	½	Hole	1	107%
8	DCIC	Absent	2	⅜	Hole	1	101%
9	DCIC	Absent	1	⅛	Slot	1	63%
10	DCIC	Absent	1	⅛	Slot	-⅜	110%
11	DCIC	Absent	1	⅛	Slot	⅜	76%
12	DCIC	Absent	1	3/16	Slot	2	79%

The CV obtained without draining holes was markedly lower than that of Test 1 (104% vs 157%), thereby indicating improvement in the distribution uniformity, despite the fact that some water was drained through the junctions of the chambers during Test 2. This resulted in consistent peak volumes being collected into containers 3, 5, 7 and 9 (Fig. 3). Owing to the substantial improvement in distribution quality attained by removing the draining hole, all subsequent tests were conducted in their absence.

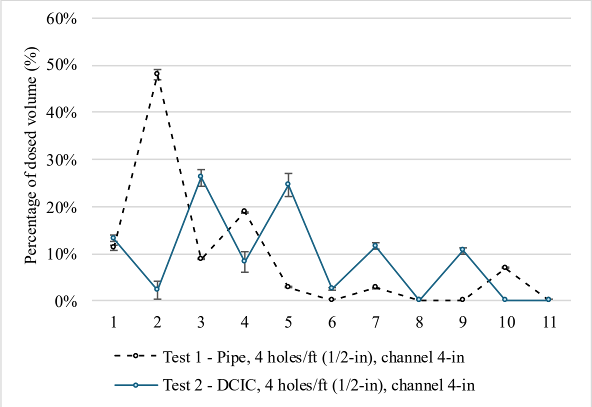

Fig. 3. Impact of the drain holes vs chamber junctions on the distribution quality along a 20-ft section dosed with water

Tests 2 to 4 involved a decreasing the perforations density along the conduits' length, with all other parameters held constant. Notably, the reduction in perforation density did not enhance distribution uniformity for the free-flow channel width of 4-in, as indicated by a CV remaining within the range of 96% to 108%. This suggests that water scarcely reached the perforations at this channel width, with most of the water exiting via the chambers' junctions (Fig. 4). Additional tests (5 to 7) were conducted using a narrower free-flow channel of 1-in. Under this narrower width, a significant improvement in distribution quality was observed as the perforations density decreased from 4 to 2 per feet of conduit (132% to 107%), reflecting a more effective solicitation of side perforations. The improved perforations utilization in the narrower free-flow channel can be attributed to their lower height from the bottom, requiring less water to reach them. As the perforations become more accessible, their density exerts more pronounced influence on the distribution quality. In the first two-thirds of the DCIC, fluctuations in water volumes collected were reduced for the 1-in channel width compared to 4-in, particularly for the scenario with 2 holes per feet (Fig. 4). Although channels of 4-in width channels exhibited slightly better distribution uniformity along the length in terms, as measured by the CV, only the few chambers' junctions are solicited. Because water exits from more openings in the narrower channels, this allows for a more even utilisation of the treatment surface, limiting point loading at the chambers' junctions.

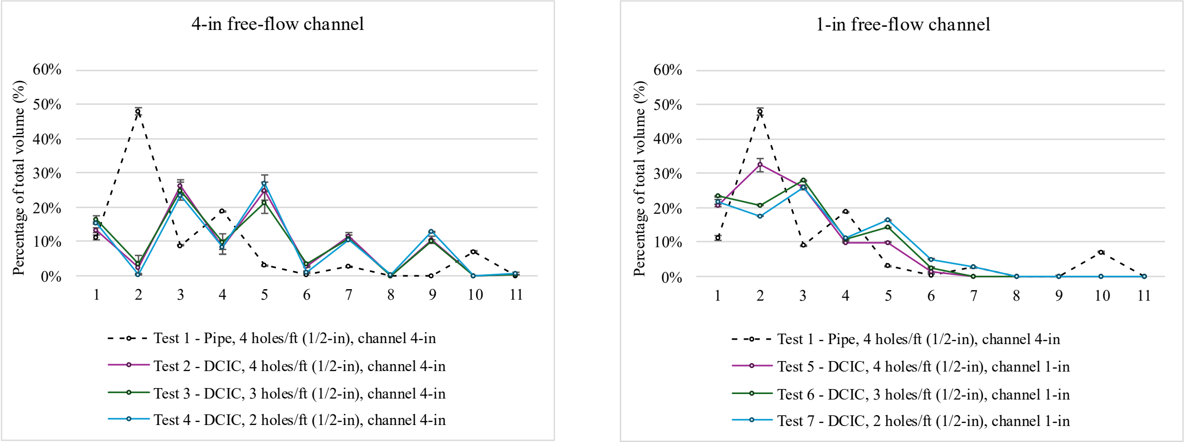

Fig. 4. Impact of the perforation density and the free-flow channel width on the distribution quality along a section of 20-ft dosed with water

Tests 7 to 9 allow the evaluation of the impact resulting from a reduction in perforations size, ranging from ½-in to ⅛-in. Since perforations smaller than ¼-in are recognized as being susceptible to clogging in wastewater applications (Dubé and Barabé 1991), perforations smaller than this threshold were drilled as 4-in long slots oriented perpendicular to the flow, rather than circular holes, to maintain their functionality despite potential debris accumulation. The density of the perforation is comparable, since the holes were placed in pairs, meaning that in each tested condition there were one set of perforation per feet. As anticipated, a substantial gain in distribution uniformity was observed whilst diminishing the size of the perforations, going from 107% for ½-in holes to 63% for ⅛-in wide slots. This enhancement in distribution efficiency is attributable to the fact that smaller perforations allow water to be released at each point, thereby facilitating the flow within the free-flow channel to reach the end of the line. Furthermore, the influence of the junction between the chamber (serving as drainage mechanism) becomes less significant. Fig. 5 shows that as the size of the perforations diminishes, less water is released at the beginning of the conduit and more at the end.

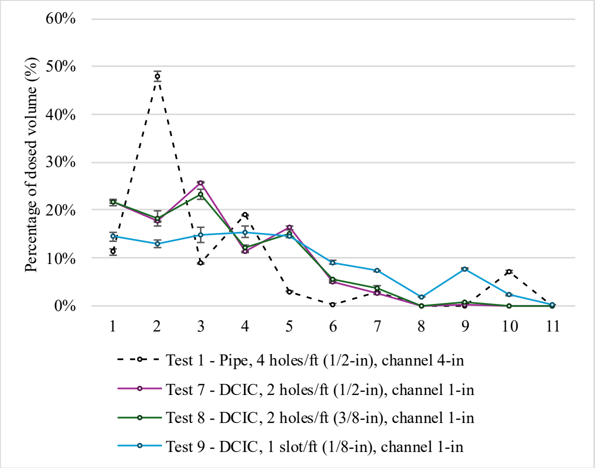

Fig. 5 Impact of the perforations' size on the distribution quality along a section of 20-ft dosed with water

Since distribution uniformity is significantly influenced by the perforations pattern when free-flow channel is narrower, additional investigations were conducted at reduced perforations sizes and free-flow channel widths. Tests 10 to 12 correspond to a free-flow channel ranging from -⅜-in to 1-in, featuring ⅛-in wide slots at a density of one perforation per foot of DCIC. A negative free-flow channel (-⅜-in) represents slots overlapping the bottom of the conduit, typical of pipes commercialized in Europe. Despite being better than the North American perforated pipe in terms of distribution uniformity (110% vs 163%), the latter configuration (Test 11) adversely affects distribution quality relative to free-flow channel scenarios, evidenced by a CV of 110% compared to 76% and 63% for ⅜-in and 1-in channel, respectively (Table 1 and Fig. 6). This outcome can be attributed to water primarily exiting the DCIC at the initial slots encountered, thereby reducing the volume of water reaching the end of the conduit. Furthermore, the presence of slots within the free-flow channel (Test 11) impedes the water flow by inducing turbulence and reducing its velocity. Nonetheless, distribution performance remains superior to that of a typical 4-in pipe, thanks to smaller slot width which facilitates an increase in water level within the DCIC, enabling it to reach the end of the conduit.

As anticipated, the smaller the perforations and the fewer there are, the more effective the distribution. Consequently, the free-flow channel width must be sufficient to allow water to reach perforations most of time during typical system operation, thus ensuring optimal usage of the underlying treatment surface. Recognizing this, it is also essential to consider the debris and sludge accumulation that will occur over time within the distribution conduits, as well as its impact on the functionality of the perforations and, consequently on distribution quality. Too small perforations are prone to rapid clogging; conversely, too few perforations may result in localized point loadings. Therefore, the optimal pattern represents a carefully balanced compromise among the size, number and positioning of the perforations. When comparing trials involving free-flow channels with diameters ranging from -⅜-in to 2-in and slots width from ⅛-in to 3/16-in (Test 10, 11 and 12), only minimal differences in distribution quality were observed, ranging from 63% to 79%. Considering structural constraint and the goal of maintaining effective distribution over time, a design incorporating a 2-in free-flow channel and 3/16-in slots was deemed a suitable compromise and was thus selected for subsequent experiments.

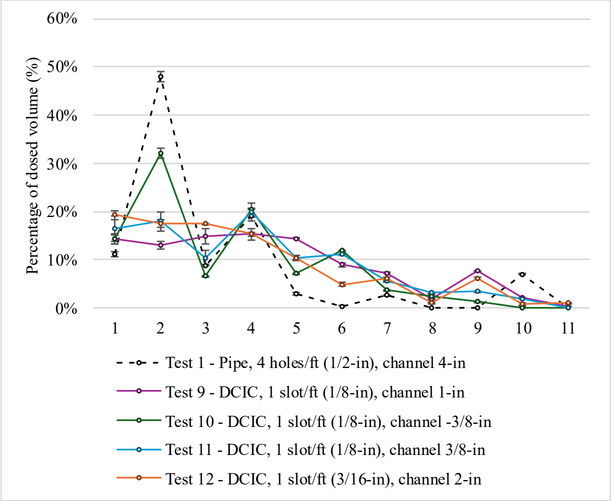

Fig. 6. Impact of the free-flow channel width for small perforations sizes along a section of 20-ft dosed with water

Impact of the Feeding Regimen on Distribution Quality

The proposed configuration, comprising a 2-in wide free-flow channel, one slots per feet (each measuring 3/16-in width and 4-in in length) and oriented perpendicular to the flow, was subjected to testing under a continuous feeding regimen at multiple flow rates. The distribution quality was evaluated and compared to a 3-in perforated pipe in order to assess the influence of the feeding regimen on performances (Table *2*). The 3-in pipe was selected due to its widespread used in wastewater treatment application within North America, and primarily because its free-flow channel more closely resembles the one in the proposed DCIC pattern.

Table 2. Impact of the feeding regimen on the distribution quality in a perforated pipe compared to the new proposed DCIC design

Test	**Material**	**Feeding regimen**	**Distribution quality** (Coeff. Var.)
12	DCIC [a]	Dosed	79%
13	DCIC [a]	2.6 gal/min	158%
14	DCIC [a]	0.50 gal/min	226%
15	DCIC [a]	0.13 gal/min	254%
16	3-in pipe[b]	Dosed	148%
17	3-in pipe[b]	2.6 gal/min	200%
18	3-in pipe[b]	0.50 gal/min	258%
19	3-in pipe[b]	0.13 gal/min	468%

a. Drain hole: absent; perforation density: 1 holes / ft; perforation size: 3/16-in; perforation geometry: slots; Free-flow channel width: 2-in.

b. Drain hole: present; perforation density: 4 holes / ft; perforation size: ½-in; perforation geometry: hole; Free-flow channel width: 3-in.

The flow rates were selected to match those typically observed at the outlet of a septic tank under typical (0.13 to 0.5 gal/min) and heavier uses (2.6 gal/min). As anticipated, increasing the flow rate applied to the treatment line leads to a much more uniform distribution, for both tested perforation patterns. A comparison of feeding regimens clearly demonstrates the benefit of dosing the water, regardless whichever of the perforations pattern employed (Table 2). Even the highest tested continuous flow rate tested did not allow water to go further than the second chambers' junction or second drainage holes, both located at more or less than 8 feet from the beginning of the line (Fig. 7). Fig. 7Regarding the impact of the narrower free-flow channel on the utilization of perforations, increasing the flow rate enhances the effective use of the perforations rather than just exiting by the drainage holes or chambers' junctions. This phenomenon is attributed to a more rapid loading of the volume necessary to reach the perforations. Dosing the water into the distribution lines allows for quick loading of the available space within the conduit, which is why this feeding approach performs so much better in terms of distribution uniformity. This further underscores the importance of implementing a dosing method to enable the water to achieve a specific velocity, thereby ensuring uniform solicitation of the of the surface involved. Nevertheless, these advantages of dosing over on-demand gravity feeding, demonstrate the benefits of the proposed pattern compared to standard perforated pipes.

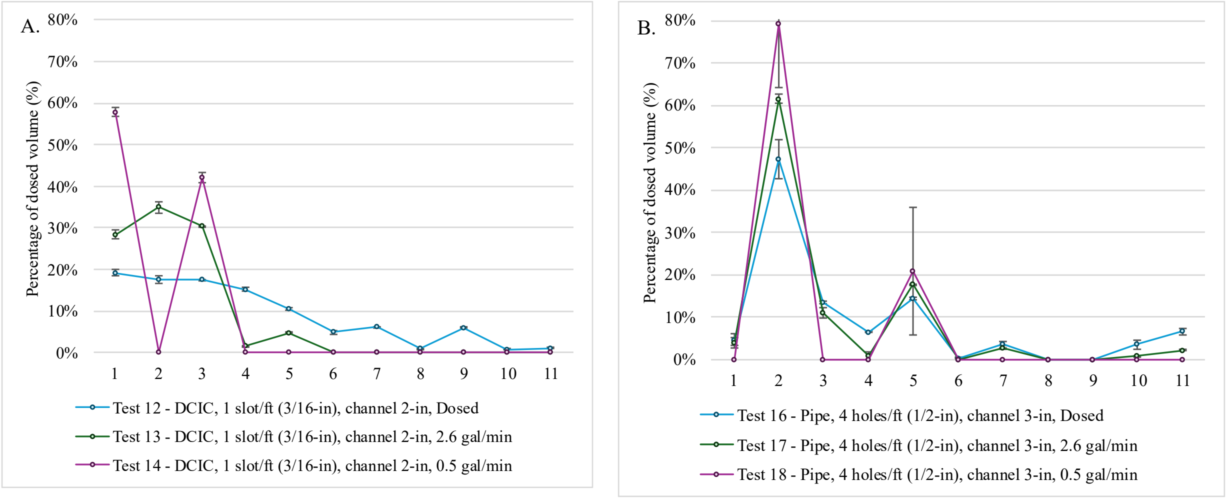

Fig. 7. Comparison of the impact of the feeding regimen on the uniformity of distribution along a section of 20-ft of a) system pipe, and b) DCIC

Robustness to installation flaws

The previous results were obtained using an experimental setup whose installation was rigorously controlled and leveled. In practical applications, it is however, acknowledged that installations will never be flawless, owing to factors such as minor to significant irregularities of surface levelling, assembly or manufacturing defects, and/or ground settlement over time. Table 3 highlights four installation deficiencies that were examined to evaluate the robustness of the DCIC in comparison to a 3-in perforated pipe.

Table 3. Installation flaws tested during this study

Scenario	**Installation flaw**
1	Counter sloped (-0.5%)
2	Sloped (+0.5%)
3	Uneven installation along the run (+0.5% and -0.5%)
4	Unaligned perforations / distribution conduit torsion

Tests 20 to 23 represent the 4 scenarios applied to the DCIC while Test 24 to 27 represent the same scenarios applied to a 3-in perforated pipe (Table 4). Counter sloped installations (scenarios 1 and 3) appears to have a greater impact on the new pattern within 4-ft long chambers than on 3-in pipes. Distribution uniformity worsened by 73% (Scenario 1) and 67% (Scenario 3) under counter slope conditions for the DCIC, whereas it decreased by 23% and 16% respectively for 3-in pipes. Despite these results, the distribution quality remained better in all cases by using DCIC with the slotted perforations pattern, with lower CV. The sloped installation slightly improved the distribution uniformity for both tested configurations, with water benefiting from the increased velocity caused by this type of installation flaw. Moreover, inducing a forced torsion on the 3-in pipe creates an improvement in distribution quality, where the CV dropped from 148% to 126%, which could be attributed to the creation of a free-flow channel between the drain holes and the side perforations. Curves presented in Fig 8Fig. 8 also highlights that some scenarios are more harmful to distribution quality, such as a counter slope (scenario 1 and 3), where up to 55% of the water exists the first drainage hole.

Table 4. Impact of the installation flaw scenario on the distribution quality under a dosed feeding regimen.

Test	**Material**	**Scenario**	**Distribution quality** (Coeff. Var.)
13	DCIC [a]	-	79%
20	DCIC [a]	1	137%
21	DCIC [a]	2	77%
22	DCIC [a]	3	132%
23	DCIC [a]	4	74%
16	3-in pipe[b]	-	148%
24	3-in pipe[b]	1	182%
25	3-in pipe[b]	2	103%
26	3-in pipe[b]	3	171%
27	3-in pipe[b]	4	126%

a. Drain hole: absent; perforation density: 1 holes/ ft; perforation size: 3/16-in; perforation geometry: slots; Free-flow channel width: 2-in.

b. Drain hole: present; perforation density: 4 holes/ ft; perforation size: ½-in; perforation geometry: hole; Free-flow channel width: 3-in.

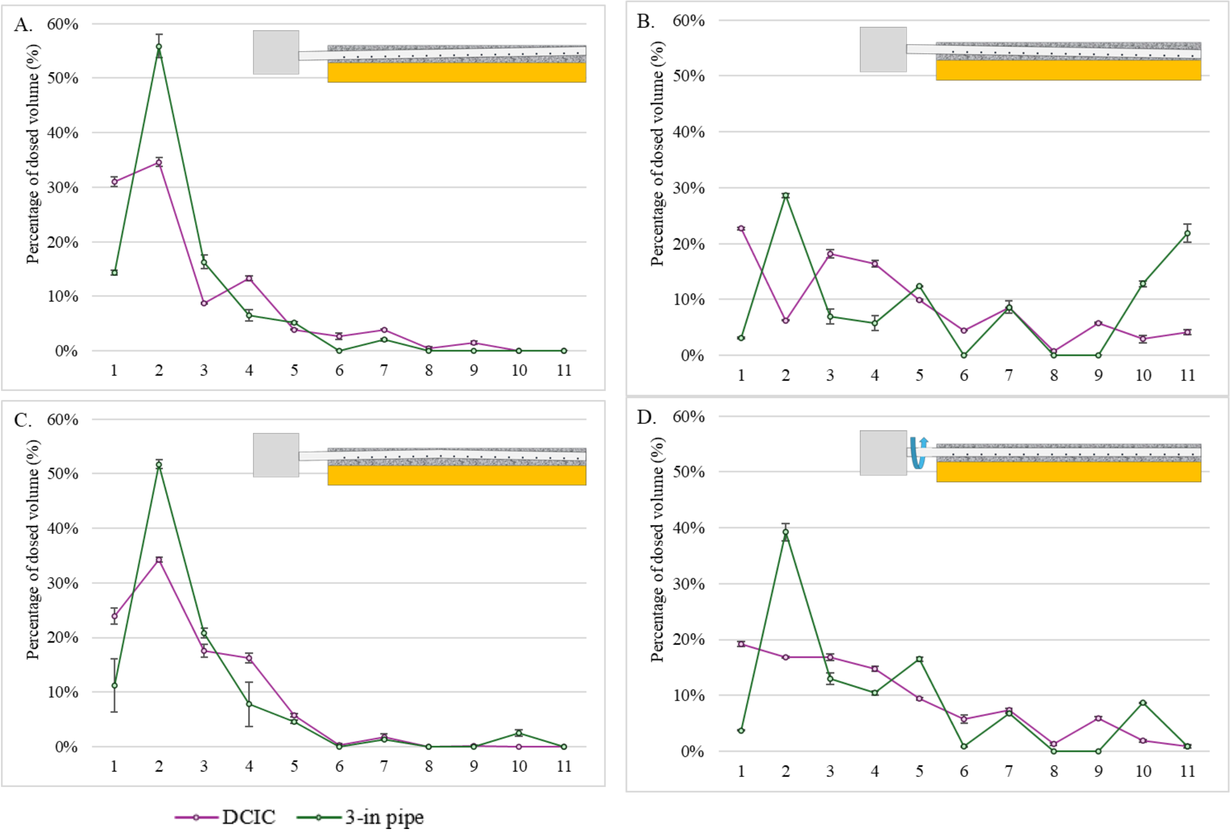

Fig 8. Impact of the installation flaw scenarios on the distribution uniformity along a section of 20-ft. A. Counter sloped (-0.5%); B. Sloped (+0.5%); C. Uneven installation along the run (+0.5% and -0.5%); D. Unaligned distribution holes / distribution conduit torsion.

Conclusion

Enhancing wastewater distribution within perforated pipes is not merely a matter of engineering but a pursuit of balance between performance, cost, and long-term operational reliability. In the onsite wastewater treatment industry, conventional approaches to treating, disposing of, infiltrating, and managing domestic wastewater have rarely been critically challenged, often relying on practices rooted in tradition rather than optimization. This work offers a fresh perspective and meaningful advancements in the field, highlighting specific improvements for perforated pipe distribution systems

This study demonstrates that optimizing perforation patterns by reducing free-flow channel width and adopting smaller slot geometries can significantly improve distribution uniformity, thus addressing the inherent limitations of conventional pipe designs. The proposed configuration, when paired with a dosed feeding regimen, achieved increased distribution consistency while maintaining robustness against common installation flaws encountered in the field.

These findings underscore the importance of thoughtful design and innovation in decentralized wastewater systems. By harmonizing hydraulic dynamics with practical constraints, we can achieve not only better system performance but also a more sustainable approach to wastewater management. As the industry evolves, this "sweet balance" will remain a cornerstone in the quest for efficient and environmentally friendly solutions.

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