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ARTICLE DE RECHERCHE / RESEARCH ARTICLE

Gas capture and extraction using multi-linear drainage géocomposite

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Abstract – The design of gas drainage systems is essential for mitigating environmental impacts, especially in contaminated soils (e.g., hydrocarbons, radon) and landfill covers (e.g., methane and carbon dioxide management). This study experimentally investigates the gas drainage capacity and transport through mini pipes within multi-linear drainage geocomposites, as these mini pipes primarily determine the system's overall drainage capacity. Initially, the assessment of the discharge capacities was performed on air, and CO_2 through various mini-pipe diameters and lengths to characterize the flow rate as a function of the gradient. Finally, the drainage capacity through mini-tube connections and their integration into the principal collection system was examined. These two steps enable the estimation of both linear and singular head losses, considering the extended lengths of the mini-pipes and their connections. The final objective is to extend these findings to gases such as methane and radon by establishing discharge equivalencies among various fluids. This experimentation is supported by well-known fluid transport concepts, allowing for the modeling and reproduction of the drained flow rate as a function of the fluid gradient. This paper presents the methodology and results of the proposed study, along with various analyses of equivalency considerations to enhance gas drainage system design.

Keywords: geosynthetics / geocomposite / drainage / gaz / landfills

Résumé – Capture et extraction de gaz au moyen d'un géocomposite de drainage multi-linéaire. La conception des systèmes de drainage de gaz est essentielle pour limiter les impacts environnementaux, particulièrement dans les sols pollués (par exemple, hydrocarbures, radon) et les couvertures de centres d'enfouissement de déchets (par exemple, pour la gestion du méthane et du dioxyde de carbone). Cette étude analyse expérimentalement la capacité de drainage et de transport du gaz par des mini-tubes placés dans des géocomposites de drainage multilinéaires, car ces mini-tubes déterminent principalement la capacité de drainage globale du système. Initialement, l'évaluation de la capacité de décharge a été effectuée avec de l'air et du CO_2 pour des mini-tubes de différents-tubes diamètres et longueurs pour caractériser le débit en fonction du gradient. Finalement, la capacité de drainage à travers les connexions des mini-tubes et leur intégration dans le système de collecte principal a été examiné. Ces deux étapes permettent d'estimer à la fois les pertes de charges linéaires et singulières, en tenant compte de la longueur totale des mini-tubes et leurs connexions. L'objectif final est d'étendre ces résultats à des gaz tels que le méthane et le radon, en établissant les équivalences entre ces différents fluides. Cette expérimentation s'appuie sur les concepts bien connus du transport des fluides, qui permettent de modéliser et reproduire la vitesse d'écoulement drainée en fonction du gradient du fluide. Cet article présente la méthodologie et les résultats de cette étude, ainsi que différentes analyses des équivalences permettant d'améliorer la conception des systèmes de drainage des gaz.

Mots-clés : géosynthétiques / géocomposite / drainage / gaz / centres d'enfouissement de déchets

1 Introduction

Drainage geocomposites are widely used to replace granular drainage materials, thereby reducing the overall environmental footprint of projects (Durkheim and Fourmont, 2010). The design of gas collection systems has a significant environmental impact on managing emissions and reducing human exposure to toxic gases. This is particularly important for applications such as:

– Sub slab depressurization systems under buildings on polluted soils (hydrocarbons, radon, etc.).
– Landfill covers and operations, where incidents like the Loscoe explosion in the UK (Williams and Aitkenhead,

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Fig. 1. Multi-linear drainage geocomposite connection scheme on the left and connections configurations on site on the right.
Fig. 1. *Schéma de connexion d'un géocomposite de drainage multilinéaire (gauche) et configurations de connexion sur site (droite).*

1991) highlight the risks associated with toxic gas pressure increases.

Integrating multi-linear drainage geocomposites with corrugated perforated mini-pipes (see Fig. 1) in these applications can:

- Provide under-slab depressurization solutions to prevent toxic gas concentration in buildings, reducing excavation, transport, and disposal of polluted soil.
- Limit the risk of gas diffusion and explosion at landfill covers.
- Maximize landfill gas (LFG) collection for renewable energy production, reducing the use of non-renewable materials like sand and gravel (Fourmont *et al.*, 2022).

Draintube multi-linear drainage geocomposites are commonly used for the above-mentioned applications as they provide high flow capacity and a connection technology that minimizes head pressure losses. Indeed, for gas applications, drainage geocomposites need to be connected to a header pipe in order to evacuate the gas outside of the system (and also apply a negative pressure in active extraction systems). This connection can induce significant head losses and limit the gas extraction capacity of the entire system. The multi-linear drainage geocomposite can be connected to the header pipe using quick connectors that allow the geocomposite mini-pipes to be mechanically plugged directly into the header. This prevents displacement during installation of the upper layers and allows for better vacuum distribution throughout the system (see Fig. 1).

This project investigates the mechanisms of gas collection and transport through multi-linear drainage geocomposites with integrated corrugated mini-pipes. Gas collection, transport, and evacuation within the system are governed by the geotextile drainage layer, the integrated mini-pipes in the geocomposite, and the main collector where the geocomposite is connected to. It is hypothesized that the overall drainage capacity of the system is predominantly determined by the mini-pipes (Faure *et al.*, 1993).

Consequently, this project aims to develop a predictive model for gas transport through the mini-pipes to optimize the design and maximize gas capture and transport systems based on specific field conditions, including gas types, site geometry, environmental factors, product configuration, and installation practices. First, the discharge capacities of air, and CO_2 through various mini-pipe diameters and configurations are experimentally accessed to express linear head losses for the various fluid tested. Additionally, experimentations of fluid transport through the connections between the mini-pipes and the main collector pipe are accessed to model singular head losses through junctions.

The objective is to extend these results to gases such as methane and radon by establishing discharge equivalencies among different fluids. Given the extended lengths of the mini-pipes and the connections between them and the main collector pipe (Fig. 1), both linear and singular head losses were quantified. This allows us to model and reproduce the drained flow rate as consistently as possible as a function of the hydraulic gradient.

This paper presents the steps and results of the proposed models, along with various analyses of equivalency considerations.

2 Background

The drainage capacity of drainage geocomposites is determined through in-plane flow capacity tests (ASTM D4716, 2013; GRI GC15, 2017; ISO 12958-2, 2020). These tests allow the determination of the in-plane flow capacity according to a given hydraulic gradient, seating time, boundary conditions and confining stress. The design parameter used to quantify the in-plane flow capacity is the hydraulic transmissivity defined as the ratio of flow rate per unit width over a hydraulic gradient.

Drainage geocomposites are typically designed to optimize their in-plane flow capacity while accounting for site-specific design loads and boundary conditions. However, these standard tests may underestimate the discharge capacity of multi-linear drainage geocomposites due to additional head losses (linear and singular) (Bourgès-Gastaud *et al.*, 2013). Indeed, because of the different physical characteristics of the drainage geocomposites, the laboratory tests performed as per the standards may be conservative. For example, the size of the testing device typically used has a length of 250 mm to 300 mm, underestimating by at least 30% the drainage capacity of multi-linear drainage geocomposites (Blond *et al.*, 2013). This is because the entrance and exit transition flow to the tested length causes additional head losses. Therefore, it is crucial to characterize the hydraulic properties of each component and develop a theoretical model for gas drainage design purposes especially through the mini pipes as they carry the largest amount of fluid. Indeed, the analytical design of these gas drainage systems relies on analogies between liquid and gas.

Fluid flow is typically evaluated using Darcy's law, and as such, the issue of laminar and turbulent flow can complicate the analysis. (Faure *et al.* 1993, 1994) and Faure and Auvin (1994) documented that the liquid flow through the mini-pipes as part of a drainage geocomposite is turbulent at gradients higher than 0.001 which allows the consideration of head losses for fluid drainage discharge capacity. The total head loss through the mini-pipes is divided into singular head losses, caused by the irregularities at the connection points, and linear head losses, due to friction along the wall of the mini-drains, as follows:

$$\Delta H_{tot} = \left(\lambda \frac{L}{D} + k\right) \frac{8}{D^4 \pi^2 g} Q^2, \tag{1}$$

with: ΔH_{tot}Total head loss through the mini-drains [m]

λ Coefficient of linear head loss [−]

L Length of the mini-drains [m]

k coefficient of singular head loss

D diameter of the mini-pipe [m]

g gravitational acceleration [m/s^2]

Q Inflow rate into the mini-drain [m^3/s]

Two dimensionless parameters are used in this study: the Reynolds number *Re*, which determines the flow regime, and the linear head loss coefficient (λ).

$$Re = \frac{QD}{S\nu} \text{and} \lambda = \frac{2giD}{(Q/S)^2}, \tag{2}$$

where: S mini-pipe section [m^2]

ν Cinematic viscosity of the fluid [m^2/s]

i flow gradient [m/m]

Indeed, Faure and Auvin (1994) established experimental evaluation of water and air discharge capacity of 2 m length mini-pipe presenting a diameter of 20 mm. According to its specific experimentations, they established and validated experimentally theoretical considerations addressing the fact that to compare the air and water flow through the geocomposite, it is assumed that, for the estimation of any fluid flow rate Q_f can be determined according to water flow rates Q_w or from another fluid using density ρ for a giver gradient as follows:

$$\frac{Q_f}{Q_w} = \left(\frac{\rho_w}{\rho_f}\right)^{1/2} = 28. \tag{3}$$

For mini-pipes, these hypotheses will be tested for air and CO_2 experimental results for extrapolation for radon and methane drainage capacity.

Additionally, some approaches have been carried out to link the friction coefficient to mini-pipes characteristics. Indeed, extending the Darcy-Weisbach equation to corrugated pipes leads to the following general equation, expressing λ, the head loss coefficient (also called *f* coefficient of friction), as a function of roughness ε and the mini-pipe internal diameter D_i from the Nikuradse approach with A and B equation parameters (Romeo *et al.*, 2002):

$$\frac{1}{\sqrt{\lambda}} = A + Bln\left(\frac{\varepsilon}{D_i}\right). \tag{4}$$

3 Laboratory Experimental Program

3.1 Linear head loss experimentation and modelling

Tests have been carried out at SAGEOS laboratory (CTT Group) to characterize the air and CO_2 flow capacity of the mini-pipes and to confirm fluid drainage equivalency presented by Faure and Auvin (1994). A new apparatus has been developed where air pressure taps are directly inserted into the mini-pipe to determine their intrinsic drainage capacity.

In this first phase, this study proposes to evaluate the air drainage capacity for three mini-pipes diameters D16, D20 and D25 presenting respectively an external diameter of 16 mm, 20 mm and 25 mm over various length (10, 20, 100 m) representing site conditions (landfill cover systems, depressurization system for building applications, etc.) to overcome disparate results and singular head losses effects.

For calculation purposes, the characteristics of the mini-pipes are presented: roughness ε, internal diameter Di and apparent diameter Dr, which represents the internal diameter Di plus the apparent roughness of the corrugation (Fig. 2 and Tab. 1).

The experimental device is presenting two air cells connecting the mini-pipe. The air flow is monitored at the entrance of the first cell by a flow meter. The air flow is then routed though the mini-pipes to the second air cell. Each cell is connected to a manometric system to allow the estimation of the head losses inside mini-pipes between the upstream and the downstream side of the system (Fig. 2).

Mini-pipes without perforations were used for these measurements to address only the linear head losses inside the min-pipe. In order to consider only linear head losses, various length of the mini-pipes was considered and three different flow meter plume were considered. To address analysis and determination of the linear head loss coefficient λ, the present methodology has been adopted. By deriving the total head loss expression, singular head loss effect can be eliminated as follows:

$$\frac{\partial \Delta H_{tot}}{\partial L} = \frac{8\lambda}{D^5 \pi^2 g} Q^2 = \alpha Q^2 = i. \tag{5}$$

By plotting the gradient *i* as a function of the square of the flow rate Q^2, it is possible to calculate the linear head loss coefficient λ for the various mini pipes diameters and the various fluid tested (air and CO_2).

Figures 3 and 4 illustrate the flow rates of air and CO_2, respectively, as a function of the air pressure gradient. A strong correlation is observed between the experimental data and theoretical modelling (Fourmont *et al.*, 2023). The linear head loss coefficient (λ) for each mini pipe was calculated using the Nikuradse equation and incorporated into the Darcy-Weisbach equation to model the resulting flow rate (Q). This highlights the precision of the experimental procedure in addressing the

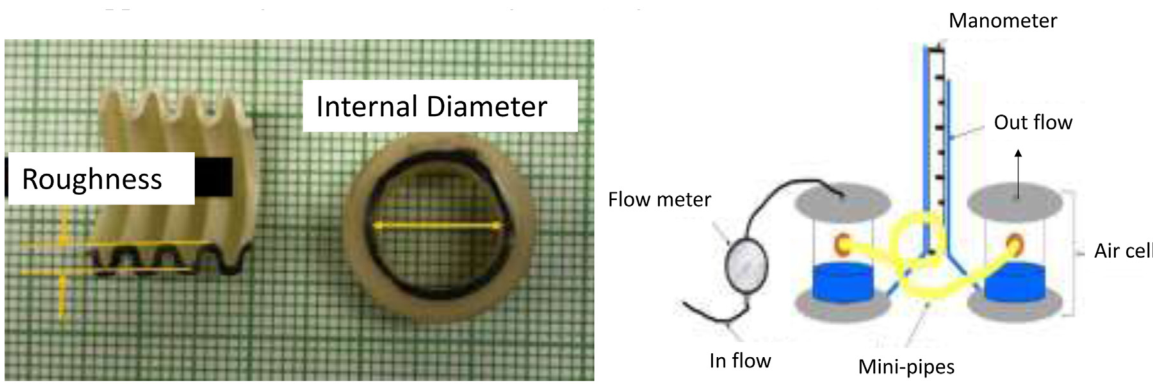


Fig. 2. Characteristics of the mini-pipes on the left and experimental set up for the determination of linear head loss assessment on the right.
Fig. 2. *Caractéristiques des mini-tubes à gauche et dispositif expérimental pour la détermination de la perte de charge linéaire à droite.*

Table 1. Summary of dimensions of mini-pipes.
Table 1. *Résumé des dimensions des mini-tubes.*

Type	Roughness, ε (mm)	Apparent Diameter, Dr (mm)	Internal diameter, Di (mm)
D16	1.9	14.2	10.4
D20	1.9	18.4	14.6
D25	2.3	22.9	18.3

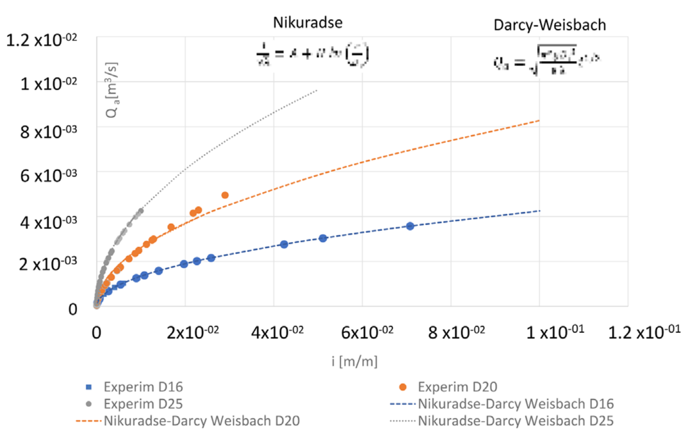


Fig. 3. Air flow rate modelling according to Nikuradse and Darcy Weisbach approach.
Fig. 3. *Modélisation des vitesses d'écoulement de l'air selon l'approche de Nikuradse et Darcy Weisbach.*

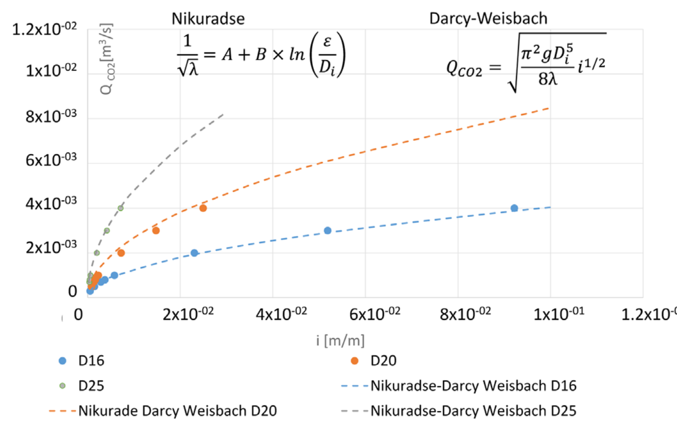


Fig. 4. CO_2 flow rate modelling according to Nikuradse and Darcy Weisbach approach.
Fig. 4. *Modélisation des vitesses d'écoulement de CO_2 selon l'approche de Nikuradse et Darcy Weisbach.*

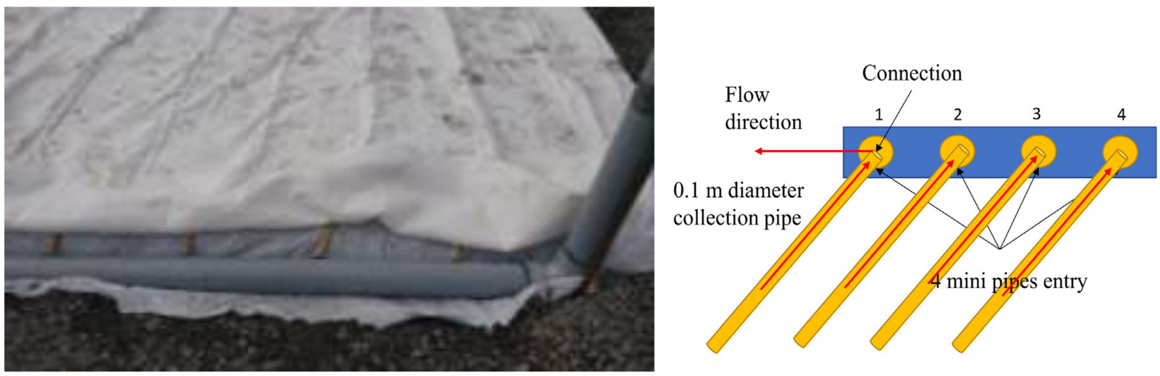
flow regime and characterizing the gas drainage capacity of the fluid through the corrugated mini pipes. Consequently, it raises the question of how confidently the equivalent drainage designs can be applied to other fluids, such as methane and radon.

3.2 Singular head loss experimentation and modelling

To increase performance of the gas collection system for applications like LFG collection in landfills or Radon mitigation under buildings, the multi-linear drainage geocomposite can be connected directly to a main header pipe using the quick connect system. This system eliminates the need for a collection trench made with gravel material and reduces the head losses between the geocomposite and the main header pipe. The resulting singular head losses due to the connection of the mini-pipes to the main collector pipe are considered. The experimental setup for measuring singular head losses is shown in Figure 5. It consists of a main collector connected to four mini-pipes. Both the upstream and downstream sections of the head loss measurement system are linked to a manometric system, as depicted in Figure 2, to precisely estimate singular head losses at the connection points. These series of tests were conducted:

- The first series evaluated the impact of the mini-pipe connection position relative to the main collection system by varying the upstream air entry point through different connections.
- The second series assessed the effect of mini-pipe length on singular head losses.

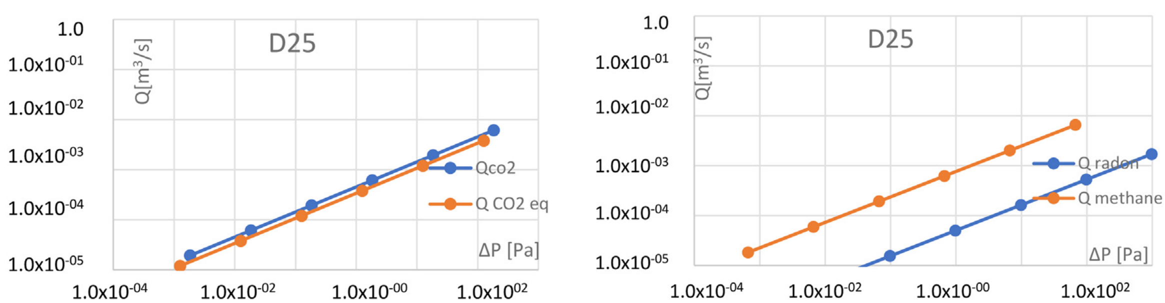
The experimental data were used to calibrate a theoretical model based on well-established hydraulic equations.



(a) **(b)**

Fig. 5. Experimental set up to address singular head loss through connection between mini pipes and the header pipe for gas drainage facilities: (a) field set up and (b) experimental set up.

Fig. 5. *Montage expérimental pour étudier la perte de charge singulière à la connexion des mini-tubes et de tuyau central pour les installations de drainage de gaz: (a) installation sur site et (b) installation expérimentale.*



(a) (b)

Fig. 6. Verification of drainage capacity equivalency between air and CO_2 on the left (a) and transposition to other fluids (methane and Radon) on the right (b).

Fig. 6. *Vérification de l'équivalence de la capacité de drainage entre l'air et le CO_2 à gauche (a) et transposition à d'autres fluides (méthane et Radon) à droite (b).*

4 Analysis and discussion about equivalency drainage capacity between fluids

4.1 Linear head loss equivalency

To verify the hypothetical drainage capacity equivalency between air and CO_2, the experimental CO_2 flow rate (Q_{CO_2}) has been compared to the equivalent flow rate calculated using the method proposed by (Faure *et al.* 1993, 1994) and Faure and Auvin (1994). The equivalency is expressed by the following equation:

$$\frac{Q_{co2}}{Q_a} = \left(\frac{\rho_a}{\rho_{co2}}\right)^{1/2} = 0.82. \quad (6)$$

Figure 6 illustrates the consistency between the experimental results and the theoretical equivalency calculation for air and CO_2 across mini-pipe diameter D25 and fluid pressure ranges tested. The same observation was made for D16 and D20. Based on these results, the equivalency of drainage capacity can be extended to other gases relevant to drainage systems, such as methane and radon (as shown in Fig. 6).

4.2 Singular head loss modelling

Singular head losses are quantified by measuring the singular head loss coefficient k evaluated experimentally using this analytical equation

$$h_s = k\frac{V^2}{2g} = k\frac{8}{\pi^2 D^4 g}Q^2 = \frac{0.0827k}{D^4}Q^2, \quad (7)$$

with:

h_s singular head loss [m]

V is the fluid velocity [m/s]

Generally, for fluids, and more specifically for gases, we can reason in terms of pressure

$$\Delta P = P_S = \rho g h_{s=}\rho k\frac{V^2}{2} = \frac{8\rho k}{\pi^2 D^4}Q^2 = 0.811\frac{\rho k}{D^4}Q^2. \quad (8)$$

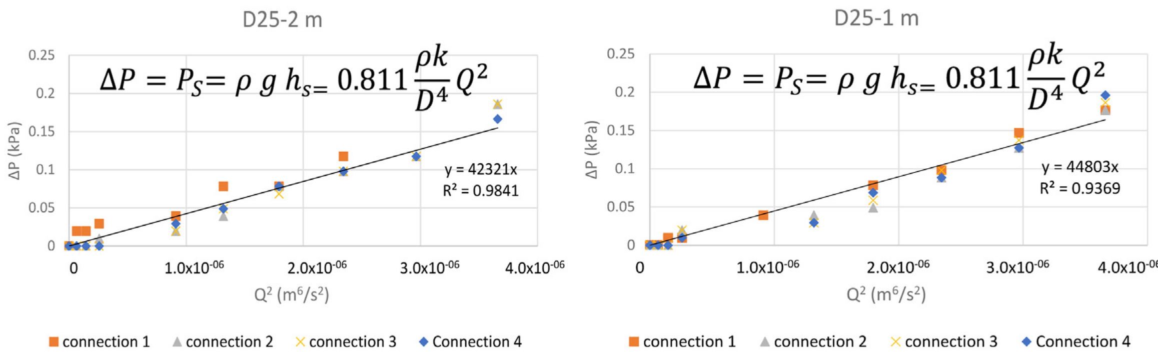


Fig. 7. Singular pressure loss ΔP as a function of the square of the air flow for a mini pipe length of respectively 2 and 1 m.
Fig. 7. *Perte de pression singulière ΔP en fonction du carré du débit d'air pour un mini-tube de longueur 2 et 1m, respectivement.*

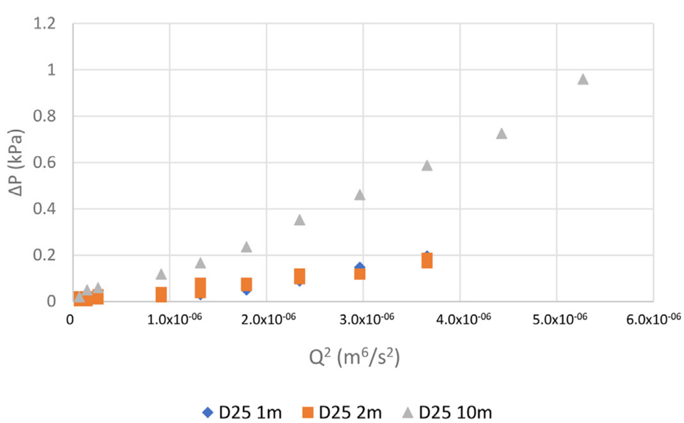


Fig. 8. Effect of the D25 mini pipe length on the total head pressure loss through the system.
Fig. 8. *Effet de la longueur du mini-tube D25 sur la perte de charge totale du système.*

Figure 7 shows experimental results of singular pressure loss ΔP as a function of the square of the air flow for a mini pipe D25 presenting 2 m length. It can be deduced that there is no effect of the position of the mini pipes through the various connections (1, 2, 3 or 4) on head losses for the given length of the collecting pipe. The same observation was made on the mini pipes D16 and D20.

To gain a deeper understanding of singular head losses, the idea was to verify the impact of the D25 mini-pipe length on the overall system head loss (1, 2 and 10 m). Figure 8 illustrates the significant influence of mini-pipe length on total head loss. A key consideration here is the inclusion of linear head loss when determining singular head losses. The total head loss is the sum of both linear and singular losses, which must be isolated for each mini-pipe diameter to accurately estimate the effect of connecting mini-pipes to the main collector. the same observation was made for the mini pipe D16 and D20.

5 Conclusion

The primary objective of this study was to experimentally and analytically evaluate the gas drainage capabilities of multi-linear drainage geocomposites. This was achieved by assessing the total head losses through the mini-pipes, which predominantly control the capture and transport of gases in landfill cover applications or in integrated under-slab depressurization systems. To model the head losses, it is necessary to quantify both linear and singular head losses in the drainage system to optimize the design of gas capture and transport systems. For the evaluation of linear head losses, the experimentation of discharge capacity through linear mini-pipes for air and CO_2 has allowed accessing equivalency for other fluid (like Radon, Methane). It is thus possible to establish discharge equivalences for gases such as methane and radon providing air drainage results, which can enhance emission management in various contexts, including contaminated soils and landfill covers. Further investigation is required to better account for the effects of singular head losses at the connection between the multi-linear drainage geocomposite and the main header within the experimental system under study.

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