Experimental Studies on Flow and Pressure Characteristics of Siphonic Drainage System with 100m piping
(Part2) Comparison with Diameters of 25mm and 20mm

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Abstract

In buildings with large floor plans such as plants, the conventional drainage system requires large piping space (height) when water is used at locations far from drainage stacks and pits. The use of siphonic drainage system in such situations can greatly reduce piping space, as the system utilizes long piping with small pipe diameters and no slope. In the previous paper, we examined the characteristics of the siphonic drainage system of 100m long actual-scale horizontal piping models using U-PVC pipes and polybutene pipes (diameter:20mm). In this paper we experimented using pipes with the diameters of 25mm instead of 20mm, examined the flow characteristics and compared the results with those of experiments with 20mm pipes.

We conducted experiments with two types of piping materials, U-PVC pipes and polybutene pipes (diameter:25mm) in 100m long actual-scale horizontal piping models, measured flow rates and pressures in the piping while water was supplied at various flow rates to the inflow part, and examined flow characteristics. We compared U-PVC pipes and polybutene pipes in different diameters and flow rates by making a flow diagram. It became clear that siphonage occurred more readily with U-PVC pipes than with polybutene pipes.

Keywords

Drainage system; siphon; siphonage; long plumbing; plant

1. Introduction

Large piping space is required in the conventional drainage system in buildings with large floor plans such as plants, where water is used some distance away from drainage stacks and pits. Siphonage drainage system can greatly reduce piping space as it makes possible the use of piping with small diameters and no slope. In earlier studies we succeeded to clarify flow characteristics in the 20m long horizontal piping using U-PVC pipes (20mm and 25mm) and polybutene pipes (20mm). And in the previous study we elucidated the flow characteristics of 20mm U-PVC pipes and polybutene pipes in a 100m long real-scale experimental apparatus.

In this study we conducted experiments using the same piping materials and length as in the previous study but with larger diameters of 25mm. We also shed some light on the flow characteristics of siphonage drainage system with long piping based on the results of the previous studies.

2. Experiments on Flow Characteristics

2.1 Outline of Experiments

2.1.1 Experimental Apparatus

The outline of the experimental apparatus is shown in Figures 1 and 2. Two types of pipes, U-PVC (25mm) and polybutene (25mm) were used. Sideway detachable drainage inlets with inflow diameters of 150mm were used. Both riser pipe elbows (50mm in height) and vent valves were constructed in the same way as in the previous study with outflow heads of 1,000mm, 1,500mm, and 2,100mm in a 100m horizontal pipe. Pressures were measured at five locations: the inflow section, 25m, 50m, 75m from the inflow section and the outflow section in U-PVC pipes, and two locations: the flow section and outflow section in polybutene pipes. Discharge flow rate and flow velocity were calculated based on the readings of the flow meter located at the outflow section.

2.1.2 Experimental Conditions

The experimental conditions are shown in Table 1. Supply flow rates to U-PVC pipes were 12L/min., 15L/min., and 18L/min., and to polybutene pipes were 12L/min., 15L/min., and 18L/min., and 22L/min. Measurements were made once for each experimental condition, 23 patterns in total.

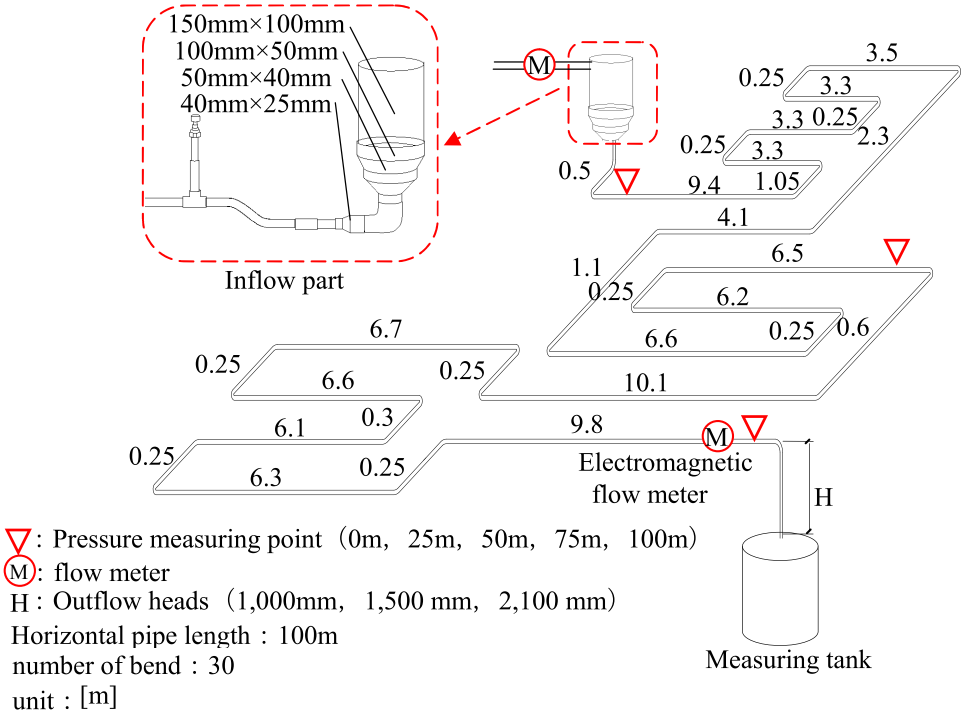

Figure 1 The outline of a piping model using U-PVC pipes

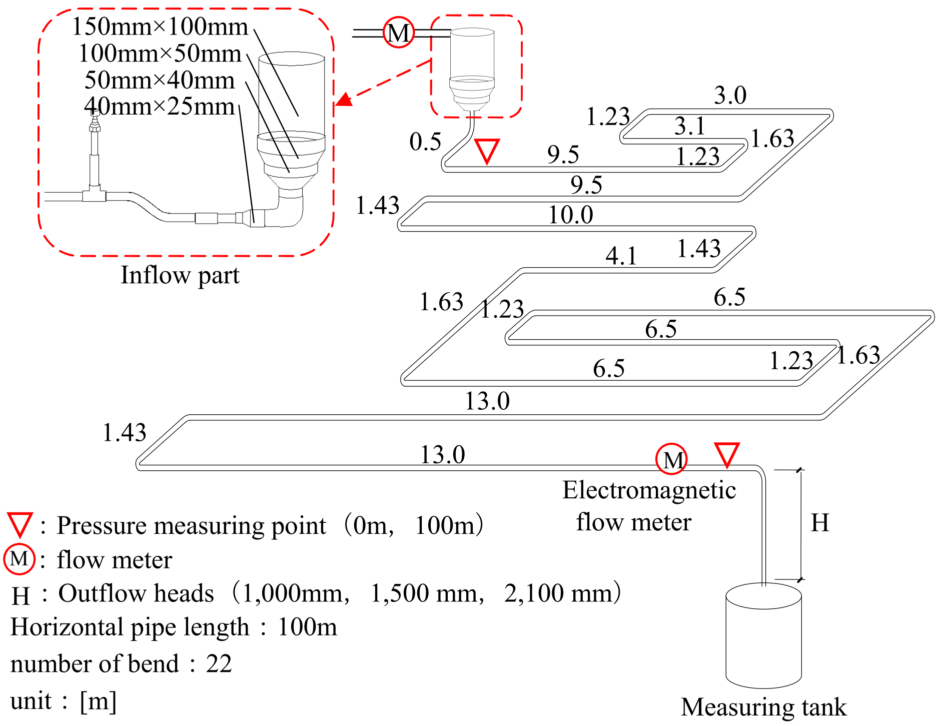

Figure 2 The outline of a piping model using polybutene pipes

Table 1 Experimental conditions

Piping material	Outflow head [mm]	Supply flow rate [L/min]
U-PVC ・Polybutene pipes (Diameter of 25mm)	1,000・1,500・2,100	12・15・18・22

（Measurement made once for each of all 23 patterns）

2.2 Results and Discussion

2.2.1 Flow phase

Figure 3 shows the distributions of pneumatic pressure and flow velocity with outflow head of 2,100mm and flow rate of 18L/min. It has been shown that bubble flow was created in U-PVC pipes leading to relatively steady pneumatic pressure and flow velocity after siphonage. On the other hand, intermittent flow was created in polybutene pipes with pneumatic pressure and flow velocity fluctuating after siphonage.

An accurate measurement could not be made in polybutene pipes at flow rates of 12L/min. and 15L/min. as separate flow resulted in small water fullness ratio in pipe.

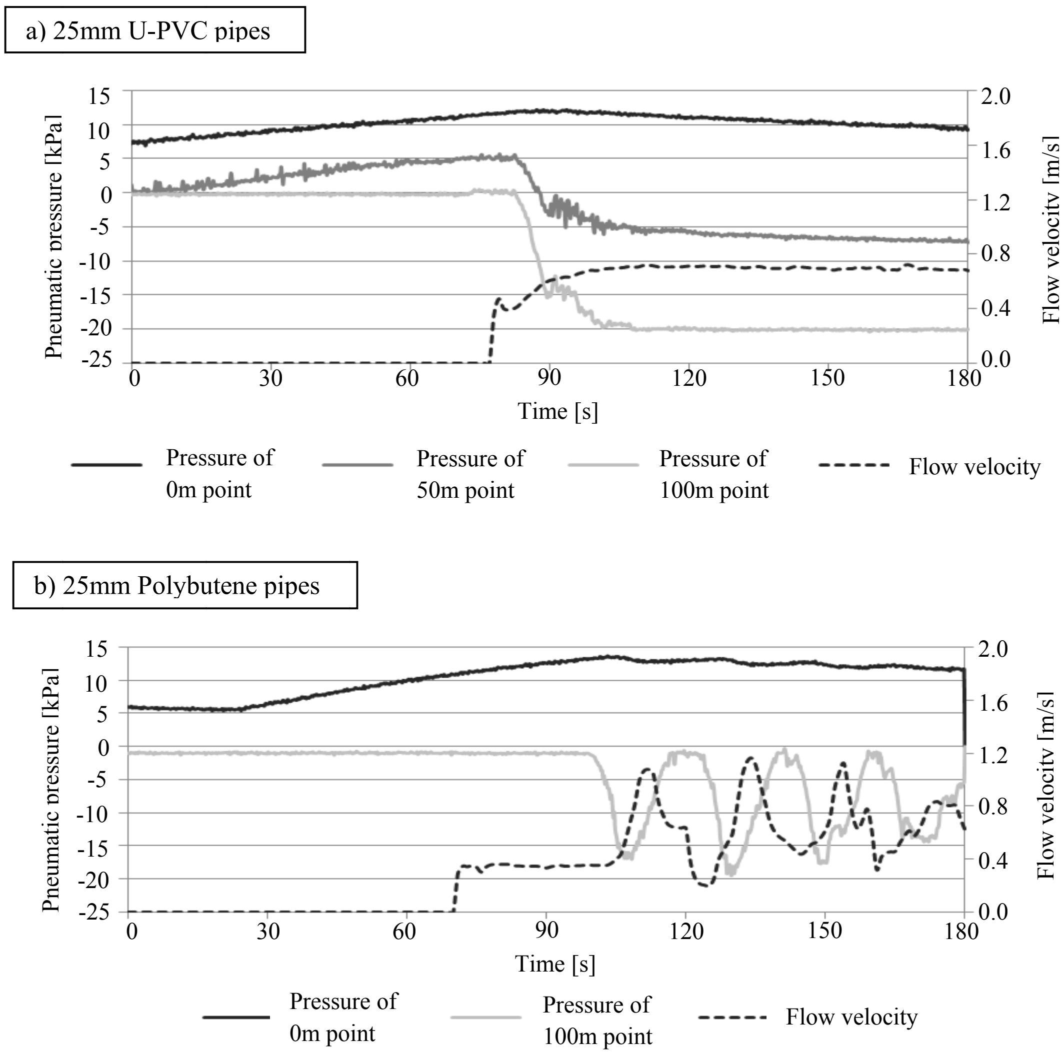

Figure 3 Distributions of pneumatic pressure and flow velocity with outflow head of 2,100mm and flow rate of 18L/min

2.2.2 Siphonic Negative Pressure

The formula for calculating siphonic negative pressure (referred to as P formula below) is shown in Table 2. The results of comparison of actual measured negative pressures with theoretical values derived from P formula for each piping model are shown in Figure 4. There have been no significant differences between actual measurements and theoretical values under any of the experimental condition. Neither have there been any significant differences in siphonic negative pressure between U-PVC pipes and polybutene pipes.

Table 2 P formula

$$P_o = \left\{ (H_a - Z_m) - \frac{(1 + \lambda \frac{L_m}{d} + \sum^{m} \zeta)}{(1 + \lambda \frac{L_a}{d} + \sum^{a} \zeta)} H_s \right\} \rho g$$

P_o : Pressure at outflow section [Pa] H_a : Height from base level to water surface [m]
Z_m : Height from base level to pressure measuring point in outflow section [m]
λ : Pipe coefficient of friction [-] L_m : Pipe length to pressure measuring point in outflow section [m]
L_a : Pipe length [m] d : Pipe diameter [m] ζ : Partial resistance [-]
H_s : Height from end of outflow section to water surface [m]
ρ : Density [kg/m^3] g : Gravity acceleration [m/s^2]

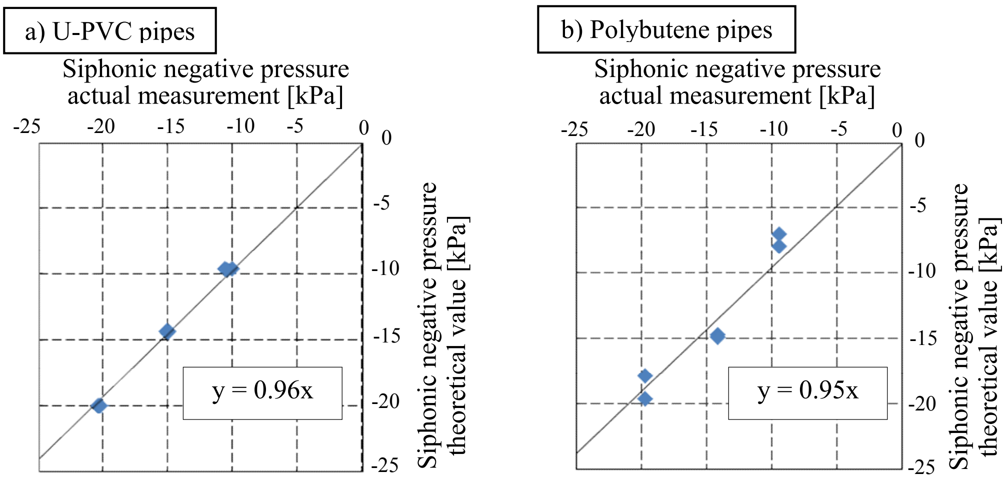

Figure 4 Comparison of siphonic negative pressure measurements and theoretical values

2.2.3 Flow Velocity

Table 3 shows the outline of the formula for calculating flow velocity (referred to as V formula below). Actual measured flow velocities and theoretical values derived from V formula are shown in Figure 5. Flow velocity was calculated from the flow rate when siphonic negative pressure reached maximum at the outflow section. Polybutene pipe tended to contributed to higher flow velocity than U-PVC pipe, which seems to be attributed to the difference in frictional resistance of the two materials. There have been some discrepancies between actual measured values and theoretical values for both types of pipe, but overall, they approximated. The reason for the differences may have been due to water fullness ratio in pipe, and in the case of polybutene pipe, air accumulation due to irregularity of the pipe material that had been rolled.

Table 3 V formula

$$v = \sqrt{\frac{2gH_s}{\underbrace{\lambda \frac{l}{d} + \sum \zeta + 1}_{\text{Equivalent pipe length } L_e}}}$$

By substituting hydraulic gradient $I = H_s/L_e$ and g = 9.8 into the equation, we get

$$v = 4.43\sqrt{I}$$

v : Flow velocity [m/s] g: Gravity acceleration [m/s^2] H_s: Siphon head [m]
λ : Pipe coefficient of friction [-] l: Total pipe length [m] d: Pipe inner diameter [m]
ζ : Partial resistance [-] L_e: Equivalent pipe length [m] I: Hydraulic gradient [-]

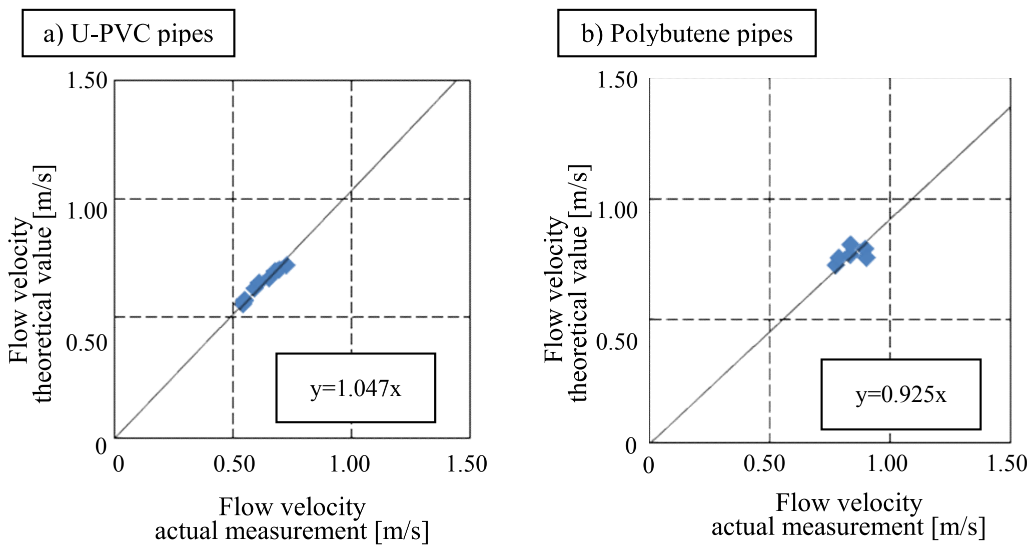

Figure 5 Comparison of flow velocity measurements and theoretical values

2.2.4 Flow Rate Charts

We created flow rate charts based on actual values and flow rates obtained by multiplying velocities in V formula by cross sections, and their relationship with square roots of hydraulic gradient. Flow rate charts of each piping model are shown in Figure 6. The regression line for polybutene pipes showed a higher gradient than that for U-PVC pipes indicating a slightly larger discharge flow rate. Actual measurements and theoretical values for the both approximated confirming the validity of theoretical values.

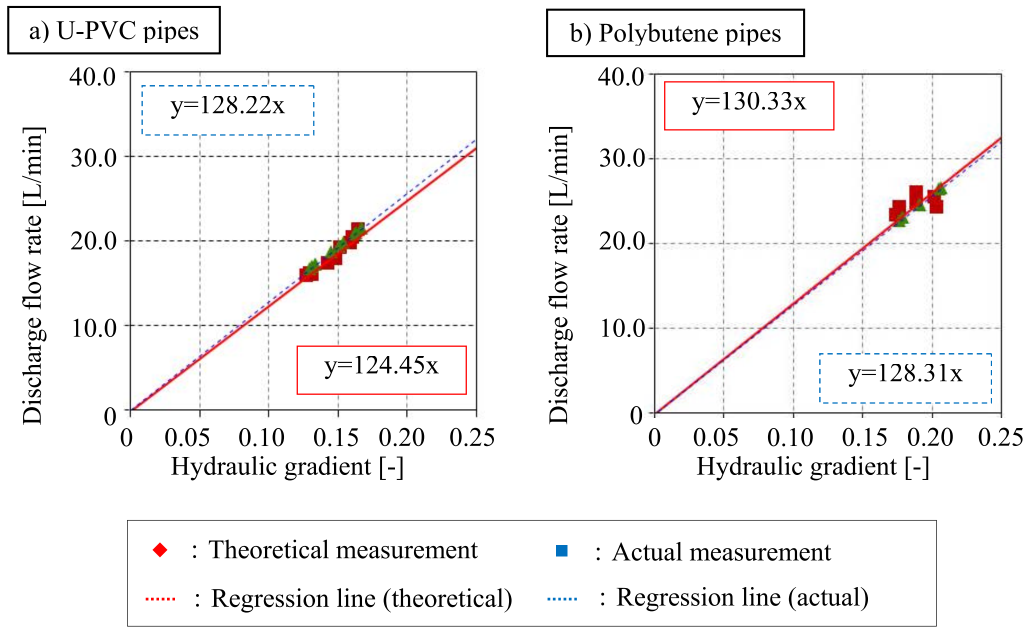

Figure 6 Flow rate chart

3. Discussion on Flow Characteristics

We examined and considered flow characteristics and siphonage negative pressure of the siphonage drainage systems constructed with U-PVC pipes and polybutene pipes based on the previous study with a 100m long 20mm pipe and the current study with a 100m long 25mm pipe.

3.1 Flow phase

It has been known that there are four possible types of flow phases in pipe: 1)separate flow, 2)intermittent flow, 3)bubble flow and 4)fill flow (Figure 7). Flow phases under each piping condition are shown in Table 4. Similar flow phases have been observed in 20mm U-PVC pipes and 20mm polybutene pipes. On the other hand, there have been some differences in flow phases with 25mm pipes; intermittent flow that does not lead to siphonage was dominant at flow rates of 12L/min. and 15L/min. in polybutene pipes, while bubble flow and fill flow were prominent in U-PVC pipes. Form this it can be safely assumed that permissible discharge flow rate is larger in 25mm polybutene pipes than in 25mm U-PVC pipes. In general, there was a tendency that flow phases with high water fullness ratio in pipe such as fill flow and bubble flow were produced as outflow heads became smaller and water flow rate increased.

3.2 Siphonic Negative Pressure

The relationship between siphonic negative pressure and supply flow rate is summarized by pipe material and pipe diameter in Figure 8, and by outflow head in Figure 9. It has been shown that pipe materials or diameters have little effect on siphonic negative pressure and it fluctuated in response to outflow head.

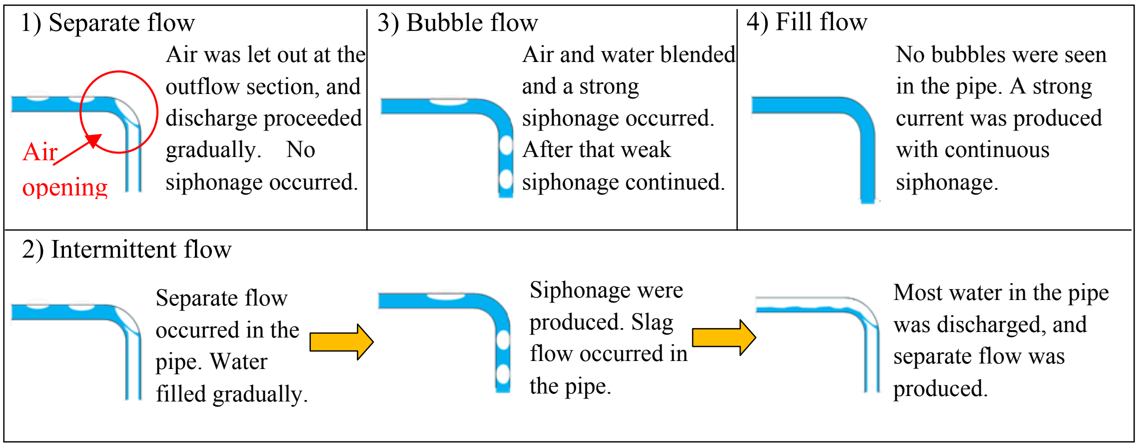

Figure 7 Flow phase diagram

Table 4 Flow phase under each piping condition

Diameter	Diameter of 20mm						Diameter of 25mm					
Material	U-PVC			Polybutene			U-PVC			Polybutene		
Flow rate [L/min] \ Ho[㎜]	1,000	1,500	2,100	1,000	1,500	2,100	1,000	1,500	2,100	1,000	1,500	2,100
6	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow						
8	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow						
10	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow						
12	Fill flow	Fill flow	Bubble flow	Fill flow	Fill flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Separate flow	Separate flow	Separate flow
15							Fill flow	Bubble flow	Bubble flow	Separate flow	Separate flow	Separate flow
18							Fill flow	Bubble flow	Bubble flow	Bubble flow	*Intermittent flow*	*ntermittent flow*
22										Bubble flow	*ntermittent flow*	*ntermittent flow*

3.3 Flow Velocity and Flow Rate

The relationships between flow velocity and supply flow rate, and between discharge flow rate and supply flow rate are shown in Figures 10 and 11 respectively. Also the relationship between discharge flow rate and supply flow rate in connection with flow phases is summarized in Figure 12. Flow velocity was found to be faster in polybutene pipes than in U-PVC pipes. Similarly, discharge flow rate tended to be larger in polybutene pipes than in U-PVC pipes. There was little difference in the relationship between supply flow rate and discharge flow rate in fill flow relative to differences in flow phase. On the other hand, discharge flow rate was 4.5 L/min. ~ 6.0 L/min. larger than supply flow rate in bubble and intermittent .

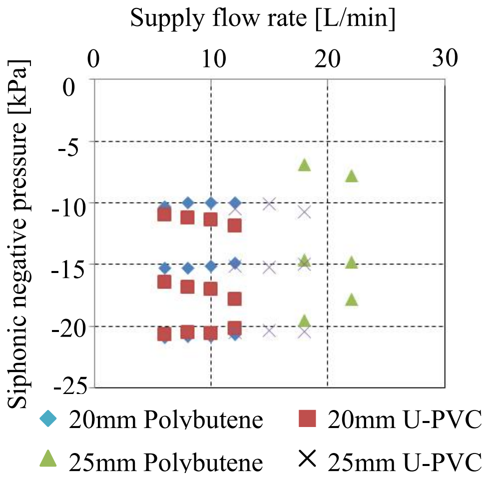

Figure 8 Siphonic negative pressure and supply flow rate summarized by pipe material and diameter

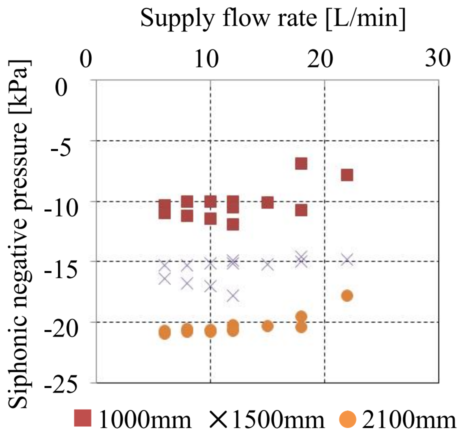

Figure 9 Siphonic negative pressure and supply flow rate summarized by outflow head

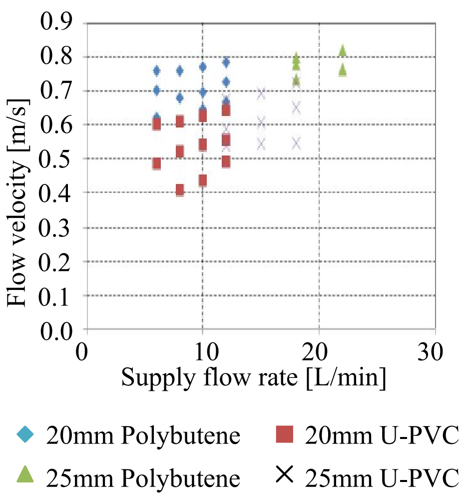

Figure 10 Flow velocity and supply flow rate summarized by pipe material and diameter

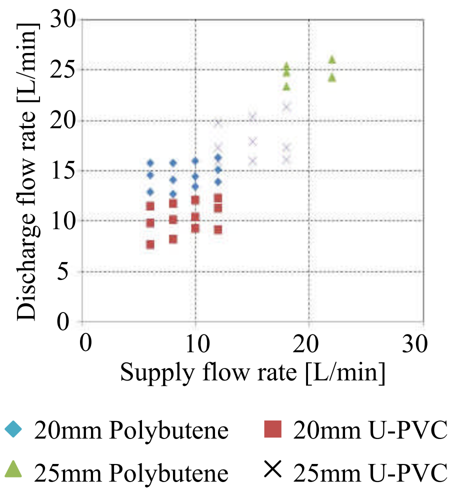

Figure 11 Discharge flow rate and supply flow rate summarized by pipe material and diameter

3.4 Maximum Water Level in Inflow Part

Figure 13 summarizes the relationship of maximum water level in inflow part with discharge flow rate by pipe material and diameter. 20mm and 25mm U-PVC pipes, and 20mm polybutene pipes indicated the maximum water level of 110cm, while the maximum water level of 25mm polybutene pipes indicated between 140cm and 167cm. This may be explained by the fact that it was more difficult to horizontally lay out 25mm polybutene pipes than 20mm pipes, and that air accumulated in irregular sections created resistance to water flow.

3.5 Hydraulic Gradient I′

Based on the assumption that which type of flow phase is to be created in a given condition is determined before water falls down from the top of the outflow pipe, we focused on hydraulic gradient I′ , that is obtained by dividing the distance from the water level inside the detachable drainage inlet to the horizontal pipe (Height: Hi) by the equivalent pipe length from the detachable drainage inlet to the top of the outflow pipe (Length: Le′).

The relationship of hydraulic gradient I′ and discharge flow rate is summarized with respect to pipe material and diameter in Figure 14. And Figure 15 summarizes their relationship with respect to flow phase. By and large, hydraulic gradients of 20mm U-PVC pipes and 20mm polybutene pipes fell within the range of 0.006 ~ 0.008 while those of 25mm U-PVC pipes fell in the 0.008 ~ 0.012 range and those of 25mm polybutene pipes in the 0.013 ~ 0.016 range.

From this it has been assumed that a certain amount of pressing force is required to initiate the movement of water for drainage even when permissible discharge flow rate has been increased by the enlargement of pipe diameters. However, as for polybutene pipes, we have yet to collect more data as their performance depends on irregularities created by piping layouts.

3.6 Flow Rate Chart

Figure 16 shows flow rate charts based on the actual measurements with 20mm and 25mm U-PVC pipes and polybutene pipes. The charts clearly indicate that polybutene pipes had larger inclination of the regression line than U-PVC pipes; hence a slightly larger discharge flow rate. As is the case with flow velocity, this can be explained by the differences in friction resistance coefficient and inside diameters.

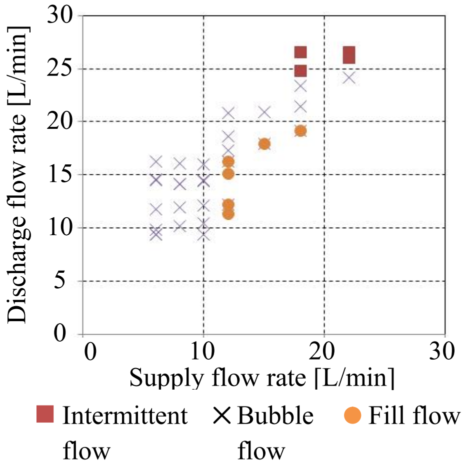

Figure 12 Discharge flow rate and supply flow rate summarized by flow phases

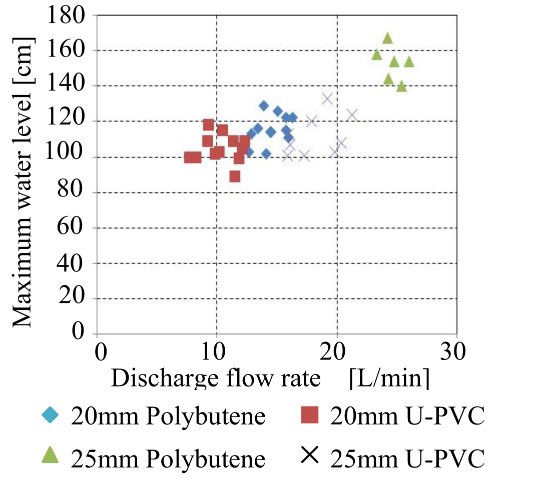

Figure 13 Maximum water level and supply flow rate summarized by pipe material and diameter

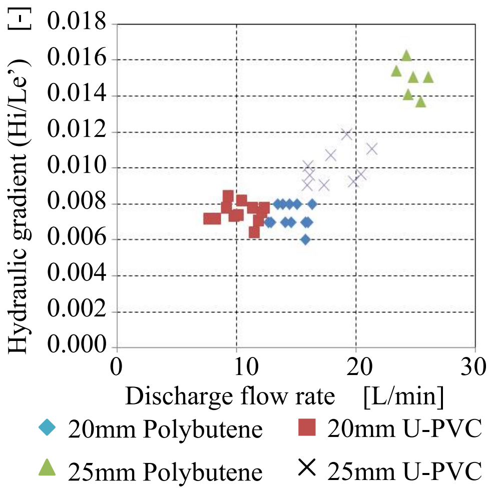

Figure 14 Hydraulic gradient and discharge flow rate summarized by pipe material and diameter

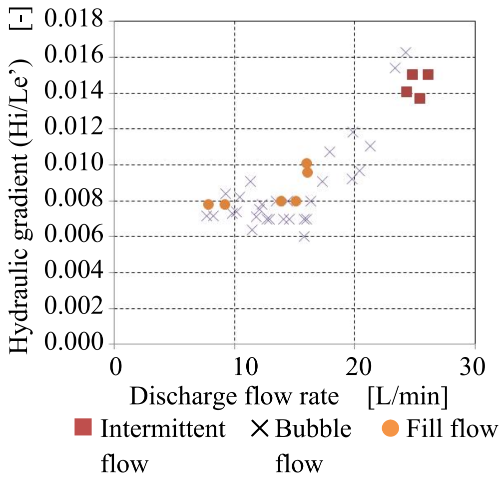

Figure 15 Hydraulic gradient and discharge flow rate summarized by flow phases

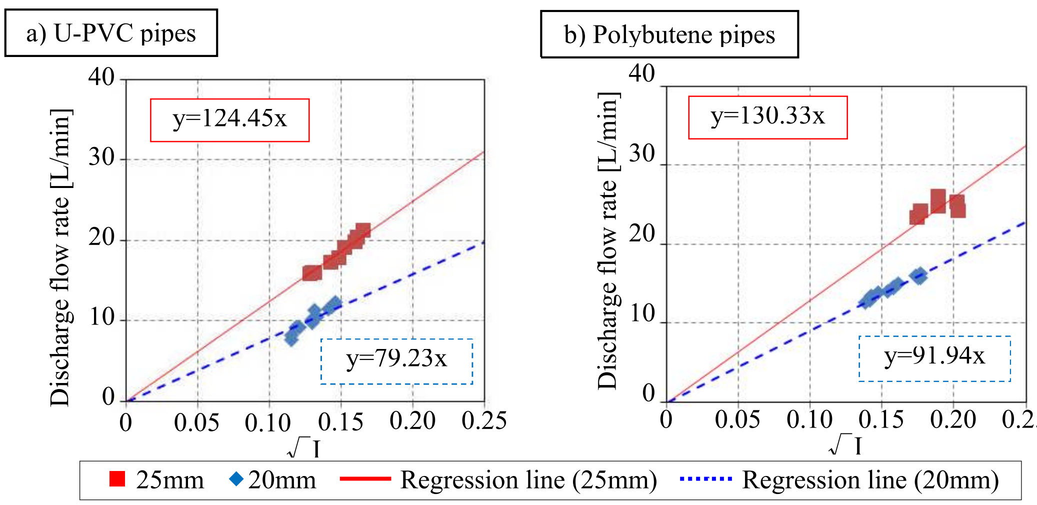

Figure 16 Flow rate charts based on the actual measurements with 20mm and 25mm U-PVC pipes and polybutene pipes

4. Conclusion

The results of the experiments can be summed up as follows:

1. We have shed some light on siphonic negative pressure and flow characteristics of 100 m long 25mm U-PVC pipes and polybutene pipes.
2. We have elucidated the tendencies of various parameters in flow characteristics, and examined how the differences in pipe material and diameter may affect flow characteristics.

As the present study only allowed a limited number of samples to base our validation on, we need to expand the number of samples for further verification of flow characteristics. Our future research should also include clarification of the effect of irregularities in polybutene pipe on flow characteristics, and appropriate pipe cleaning methods to resolve pipe clogging that is likely to occur in pipes with small diameters.

5. Reference

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