Application of the siphonic drainage system to long plumbing intended for use in plants

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Abstract

Studies on the siphonic drainage system intended for fixture discharge in buildings have seen some progress in recent years particularly on the subjects such as flow characteristics, and there have been several examples of application to fixture drainage in actual apartment complexes.

On the other hand, a large piping space (height) is required in the conventional drainage method based on slope when a water use places are isolated in buildings such as plants where the floor planning tend to be large. The use of the siphonic drainage system makes it possible to construct long plumbing with small pipe diameters and no slope, which could shorten a large piping space.

In this study we conducted experiments on flow characteristics using actual scale experimental models with a 20 m long horizontal pipe and analyzed the results of the experimental data to study application of the siphonic drainage system to long plumbing intended for use in plants.

Keywords

Drainage system, siphon, the long plumbing, plant, fixture discharge

1 Introduction

The study of the siphonic drainage system intended for fixture discharge in Japan began in 1999 based on the concept of SI housing, which was grown out of the impetus to promote long life apartment houses. High expectation is held for the siphonic drainage system as a low-cost, highly flexible system that can replace the existing system when the layouts of fixtures in buildings are renewed. The application of the system is now evolving from laboratories and desk plans to field experiment with test applications to existing apartment houses with tenants having already been made.

Having advantages of fitting in with smaller diameter piping than the conventional drainage system and not requiring sloped horizontal drain pipes, the system may have wider applications other than the use in apartment houses. One possibility is the use in plants and factories. The conventional drainage system, if installed in buildings where the floor planning is large and water use places are isolated in buildings, requires a large piping space (height). On the other hand, the use of the siphonic drainage system is expected to reduce such space.

In the previous study in 2008 on the application of the siphonic drainage to fixture discharge, Sakaue demonstrated how the differences in discharge style affected flow characteristics by calculating equivalent lengths of the pipes that made up the system and flow velocity in piping. In 2010, Tanaka, Sakaue, et al. evaluated the performance of riser elbow pipes that contributed to induce a siphonic effect with its raised horizontal pipe ends. They confirmed the validity of the equation for calculating siphonic negative pressure as well as that of the equation for calculating velocity.

In this present study we conducted a real scale experiment using a 20 m long horizontal pipe to obtain data for application of the siphonic system to long piping. We used the equation for calculating velocity and the equation for calculating siphonic negative pressure obtained in the previous study to make comparison with experimental data and confirm the validity of these equations.

In Chapter 2, we investigated how flow characteristics were influenced by the shapes of inflow sections of the indirect waste pipes that receive discharge from production facilities of plants.

In Chapter 3, we investigated the influence that different diameters (20A and 25A) of U-PVC pipes had on flow characteristics.

2 Influence of Shapes of Inflow Sections on Flow Characteristics

2.1 Outline of Experiment

2.1.1 Purpose

The purpose of this experiment is to examine the influence of the shapes of inflow sections that receives discharge from production facilities of plants and to determine the most appropriate shape of inflow sections.

2.1.2 Experimental apparatus

The outline of the piping model is shown in Figure 1. The inflow section is a tube shaped part (referred to as inflow part below) which is made up of the combination of a drainage hopper and a straight pipe, and two diameter patterns 100A and 150A were prepared (Figure 2). A U-PVC pipe (25A) with a horizontal length of 20 m and variable outflow heads of 500, 1,000, 1,500 and 2,000 mm were used. Two patterns of piping forms: basic piping and riser piping (a combination of a vent valve [Photograph 1] and a riser elbow pipe [Figure 3]) were used.

Pressures were measured and a video camera was set up at the inflow section and the discharge section. Flow rate and flow velocity were calculated from the pressure values measured by a sensor attached to the measuring tank.

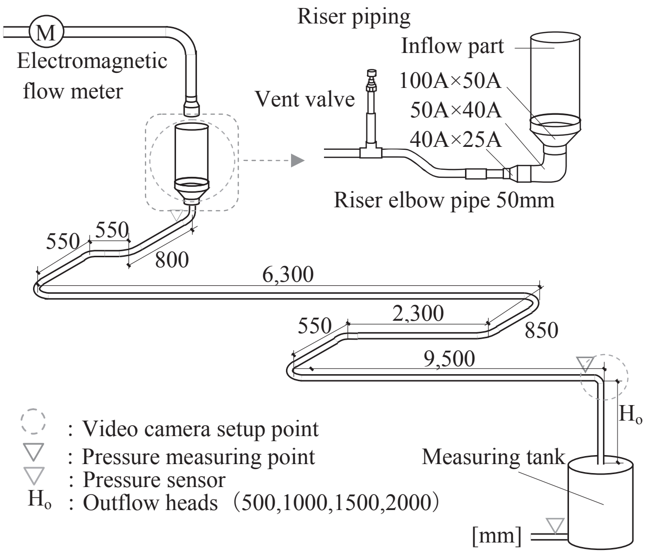


Figure 1 - The outline of a piping model using 25A

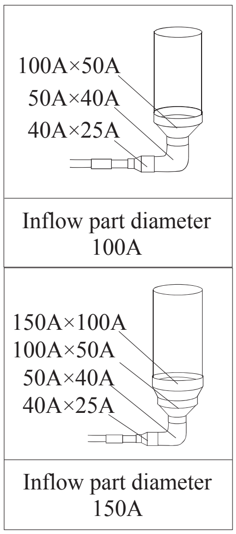


Figure 2 - The shape of inflow part

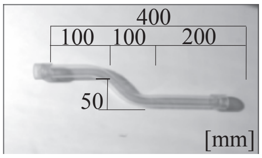
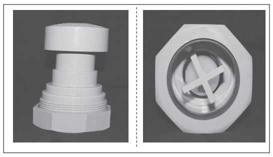


Figure - 3 The shape and dimension of riser elbow pipe 50



Photograph - 1 Vent valve (Left: Front Right: Bottom)

2.1.3 Experimental condition

The experimental conditions are shown in Table 1. They consist of 2 patterns of piping form: basic piping and riser piping, 2 patterns of inflow part diameters: 100A and 150A, 6 patterns of supply water volume: 10, 12, 24, 30, 36L/min. , and 4 patterns of outflow head: 500, 1,000, 1,500, 2,000 mm. The discharge style simulated indirect discharge by running water used in production plants. Measurements were made twice in each of 96 experimental conditions in total.

Table 1 - Experimental conditions

Piping form	Inflow part diameter [A]	Horizontal pipe length [m]	Outflow head Ho [mm]	Water supply volume [L/min]
Basic piping • Riser piping	100 • 150	20	500 • 1,000 • 1,500 • 2,000	10 • 12 • 18 • 24 • 30 • 36

(Measurement made twice for each of all 96 patterns)

2.2 Results and Consideration

2.2.1 Siphonic negative pressure

The equation for calculating siphonic negative pressure (referred to as Equation P below) is shown in Table 2. The results of comparison of actual measured negative pressures with theoretical values derived from Equation P by piping model are shown in Figure 4.

Judging from the inclination of the regression line, the differences in inflow part diameters or piping form did not seem to have any significant influence on siphonic negative pressure. The actual measured pressures and theoretical values tended to approximate with a slight leaning of theoretical values toward the negative pressure side (0.6 ~ 5.4%).

The values of partial resistance(ζ) regarding inflow part 100A, inflow part 150A, riser elbow pipe, and 90° elbow pipe were substituted in the equation: 0.96, 1.34, 0.65 and 0.30 respectively.

Table - 2 Outline of P equation

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

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]

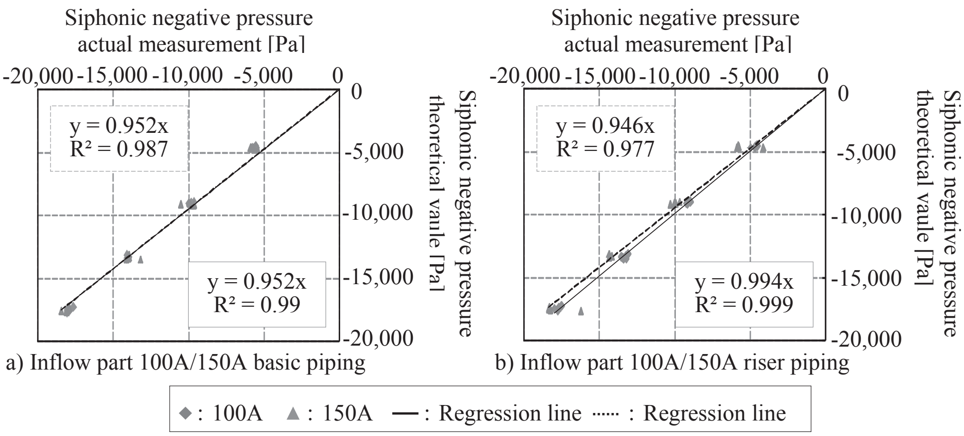


Figure - 4 Comparison of siphonic negative pressure actual measurements and theoretical values

2.2.2 Flow velocity

Table 3 shows the outline of the equation for calculating flow velocity (referred to as Equation V below). Figure 5 shows the results of comparison between inflow parts diameter 100A and 150A in each piping model. The comparison of the actual measured velocities with theoretical values derived from Equation V is shown in Figure 6. The actual measured velocities in Figure 6 are those measured when siphonic negative pressures were at maximum.

As seen in the inclination of the regression line in Figure 5, there was little difference in flow velocity in pipe attributable to inflow parts diameter. Nor was there any significant influence of piping form on flow velocity. The actual measured pressures and theoretical values tended to approximate with a slight leaning of theoretical values toward the negative pressure side (-0.2 ~ 4.1%). From this it was confirmed that there was little influence of inflow parts diameter or piping form on flow velocity.

Table - 3 Outline of V equation

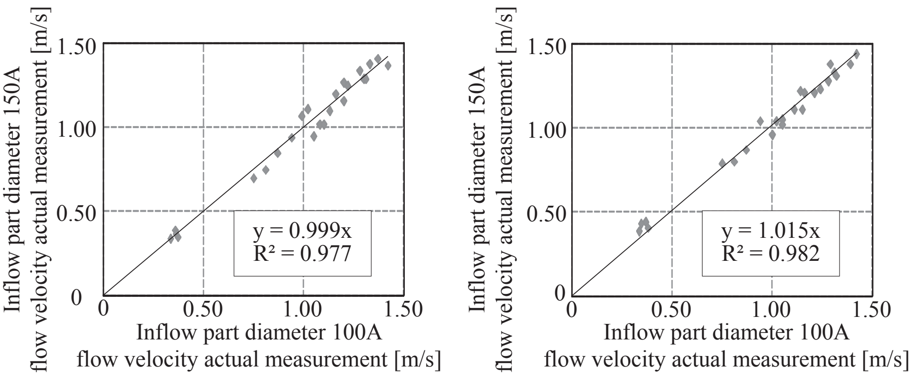
$$v = \sqrt{\frac{2gH_s}{\lambda \frac{l}{d} + \sum \zeta + 1}} \qquad \cdots\cdots (2)$$

Equivalent pipe length L_e

By substituting hydraulic gradient $I = H_s/L_e$ and g = 9.8 into the equation (2) , we get

$$v = 4.43\sqrt{I} \qquad \cdots\cdots (3)$$

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 [-]



a) Basic piping b) Riser piping

Figure - 5 Comparison of flow velocities by inflow part diameters

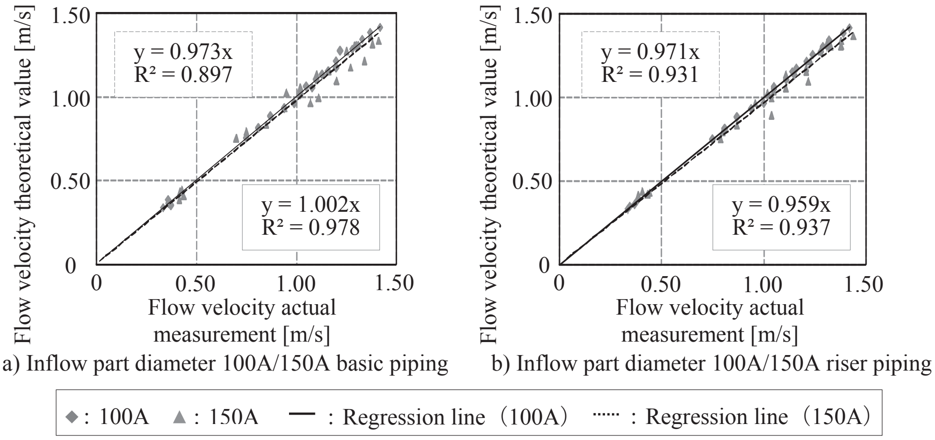


Figure - 6 Comparison of flow velocity actual measurements with theoretical values

2.2.3 Flow rate chart

Flow rates were calculated from actual measured velocities and theoretical values, and flow rate charts were drawn based on the relationship between the flow rates obtained from calculation and hydraulic gradient. Flow rate charts for each inflow parts diameters and piping form are shown in Figure 7. The actual measured values and theoretical values approximated in each experimental condition, and the coefficient of determination was also high. Consequently, it follows that discharge flow rates in the siphonic drainage system that is made up of U-PVC pipes (25A) can be successfully selected based on flow rate charts.

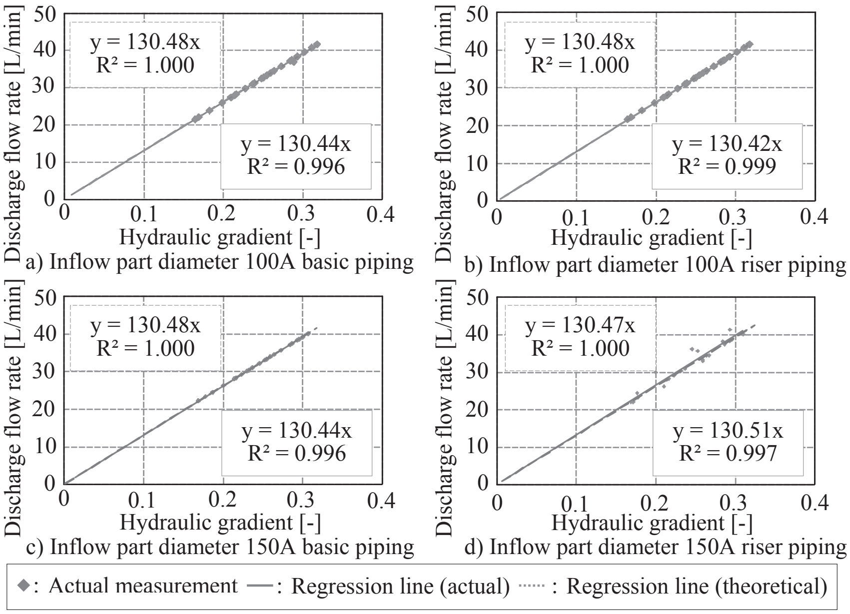


Figure - 7 Flow rate diagram

2.2.4 Maximum water level in inflow part

Figure 8 shows the relationship of maximum water level in the inflow part to outflow heads in each piping model. The maximum water level in the riser piping was found to be approximately 50 mm higher than that in the basic piping. The reason for this seems to be partial resistance in the riser piping.

In comparing the inflow part diameter 100A and 150A, no significant differences in maximum water level were noted when water supply was 10 L/min. and 12 L/min., but when water supply was 18 L/min. or more, water level rose about 23 mm on average with the inflow part diameter 100A every time water supply increased by 1 L/min. while water level rose about 17 mm on average with 150A. This seems to indicate that the inflow part diameter 150A was more effective in preventing the water level from rising than 100A.

In terms of outflow head, the maximum water level was seen with the 500 mm outflow head at the water supply rate of 36 L/min. Other than that no significant difference was found in water level among different outflow heads. It can be assumed that discharging capacity outmatched water supply volume in other conditions while the small siphon head in relation to water supply volume with the 500 mm outflow head at 36 L/mm kept the flow velocity and rate low allowing the water supply volume to exceed the discharging capacity and causing the water level inside the inflow part to rise. But after that the siphon head rose with increasing water level, and as a result a larger hydraulic gradient was created, which in turn pushed up the allowable drainage volume, preventing overflow.

Overflow occurred in a basic piping layout with the inflow part diameter 100A, the outflow head 500 mm and water supply volume 36 L/min. Therefore, this piping layout was excluded. Maximum water level in each experimental condition was checked visually.

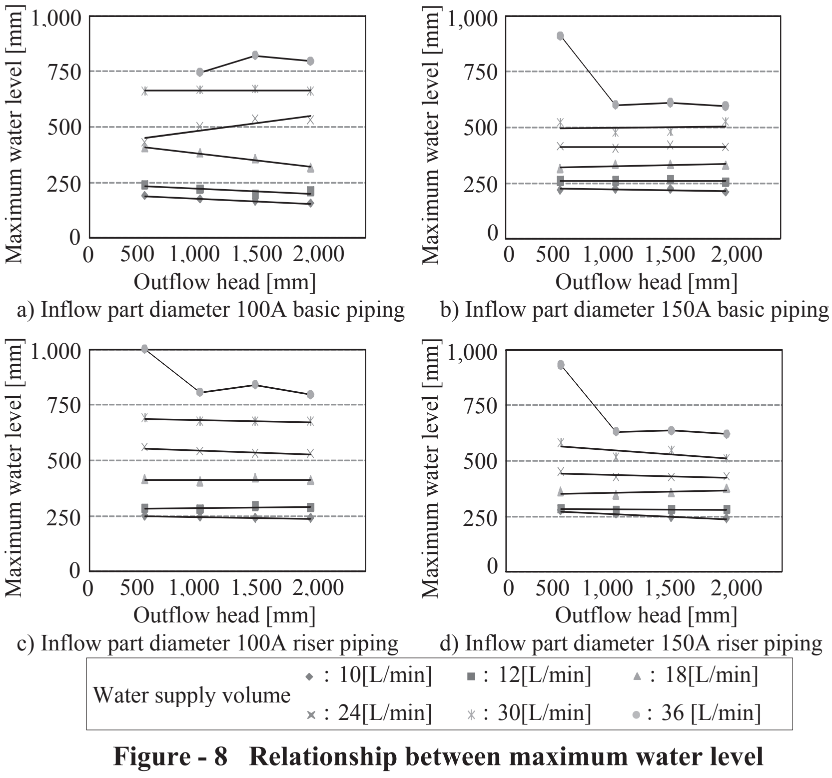


Figure - 8 Relationship between maximum water level and outflow head by piping model

3Comparison of Flow Characteristics in 20A and 25A Horizontal Pipes

3.1 Outline

3.1.1 Purpose

The purpose of the experiment was to investigate the effect of pipe diameter on flow characteristics by comparing horizontal pipes 20A and 25A.

3.2 Results and Consideration

3.2.1 Maximum water level in inflow part

Comparison of maximum water level in inflow part between 20A and 25A horizontal pipes in the basic piping is shown in Figure 9, that of maximum water level in inflow part between 20A and 25A horizontal pipes in the riser piping in Figure 10.

The water level rose about 35 mm on average with the inflow part diameter 20A every time water supply increased by 1 L/min. while with 25A the water level rose about 23 mm on average. It was confirmed that 25A, having a larger flow rate, was more effective in preventing the water level from rising than 20A; the water level rose 100 mm at water supply rate of 10 L/min. and 150 mm at 12 L//min.

Though the maximum water level was reached with 20A, outflow head 500 mm at water supply rate of 18 L/min., there was no significant difference in maximum water level attributable to the difference in outflow head.
Overflow occurred with the inflow part diameter 20A at water supply volume of 36 L/min. As a result, this piping layout was excluded. Maximum water level in each experimental condition was checked visually.

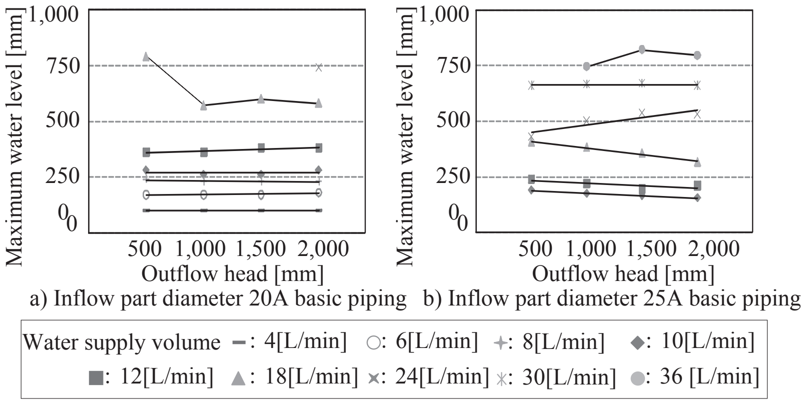


Figure - 9 Comparison of maximum water level with 20A and 25A in basic piping

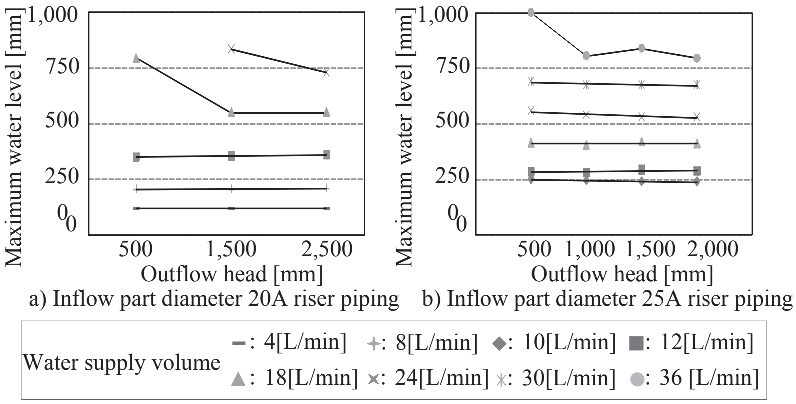


Figure - 10 Comparison of maximum water level with 20A and 25A in riser piping

3.2.2 Flow phase

Characteristic flow phases with inflow part diameters 20A and 25A are shown in Table 4, and their diagram in Figure 11.

To avoid deposition of solids in the piping or overflow from the inflow part, it is necessary to determine the diameter where bubble flow or intermittent flow occurs in actual use. Siphonic effects tended to occur earlier with 20A than with 25A. Bubble or intermittent flow occurred with 20A at water supply volume of 6~12 L/min. However, water overflowed from the inflow part when water supply volume was 18 L/min. or more due to low flow velocity and small flow rate of 20A diameter. On the other hand, 25A with its larger flow rate successfully coped with large water supply of 12~30 L/min. From these results it can safely be concluded that careful selection of inflow part diameter (20A or 25A) is essential to match water supply volume and outflow head in its application to the siphonic drainage system.

Table - 4 Flow phase in diameter 20A pipe and 25A pipe

Water supply volume [L/min]	Diameter 20A				Diameter 25A			
	Outflow heads [mm]							
	500	1,000	1,500	2,000	500	1,000	1,500	2,000
4	Separate flow	Separate flow	Separate flow	Separate flow				
6	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow				
8	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow				
10	Bubble flow	Intermittent flow	Intermittent flow	Intermittent flow	Separate flow	Separate flow	Separate flow	Separate flow
12	Fill flow	Bubble flow	Bubble flow	Bubble flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow
18	No discharge	Fill flow	Fill flow	Bubble flow	Bubble flow	Intermittent flow	Intermittent flow	Intermittent flow
24	No discharge	No discharge	No discharge	Fill flow	Bubble flow	Bubble flow	Intermittent flow	Intermittent flow
30					Fill flow	Fill flow	Bubble flow	Bubble flow
36					No discharge	Fill flow	Fill flow	Fill flow

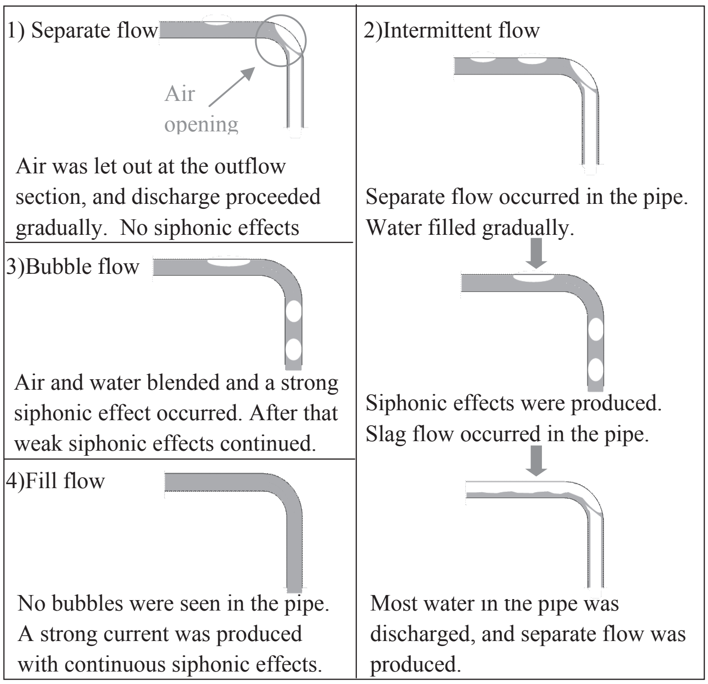


Figure - 11 Flow phase diagram

4 Conclusion

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

＜Chapter 2＞

(1) No significant effects attributable to difference in inflow parts (100A or 150A) on pneumatic pressure in pipe and flow velocity were seen.

(2) There was a difference in water level rise in pipe of approximately 50 mm between the basic piping and the riser piping.

(3) Inflow part diameter 150A showed smaller water level rises than 100A except in conditions with low water supply volumes.

＜Chapter 3＞

(1) The use of 25A diameter enabled discharge of larger volume of water than 20A diameter.

(2) Smaller water level rises in the inflow part were observed with 25A diameter than with 20A diameter.

The present study has raised the following issues to be addressed in the future: to clarify the effects of various discharge styles, pipe materials and piping forms on flow characteristics and to expand the scope of design materials for the siphonic drainage system.

Particularly of interest are verification of flow characteristics in 50 m and 100 m long piping layouts made up of U-PVC pipes and that of flow characteristics in long piping made up of 20A diameter stainless steel pipes. Also it is necessary to consider appropriate pipe cleaning methods to counteract pipe clogging that is likely to occur in pipes with small diameters.

5 Reference

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6 Presentation of Authors

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