REDUCTION OF THE RESIDUAL AMOUNT OF NOXIOUS LIQUID SUBSTANCES IN THE PIPING SYSTEM OF CHEMICAL TANKERS AFTER UNLOADING PROCEDURE OF CARGO

(PART 2 : REDUCING EFFECT OF RESIDUE IN THE DISCHARGING OPERATION WITH THE LINE BLOWING-EXPERIMENT) *

BY

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ABSTRACT

The discharge of noxious liquid substances or contaminated water genarated during the tank cleaning, line washing and tank ballasting from chemical tankers into the sea is regulated by the new international convention for the prevention of marine pollution. For the practical enforcement of the regulation, the accurate estimation of actual amount of residual liquid substances and the investigation on measures for minimizing the amount of residue have been required.

The investigation of the line blowing which is commonly applied to the present chemical tankers after unloading for reducing the quantity of residue in the piping arrangement is reported. Experiments were performed with the laboratory test facilities using water and air as the working fluid. In accordance with the test procedures of the regulation, the test arrangement is provided to maintain a back pressure with the 10 m. long vertical riser pipe or the constant pressure valve set at 1 bar minimum at the end of the horizontal or inclined pipe. The results of observations of air and water flow and the measurements of quantity of remaining water in the horizontal or inclined pipe are described. The effects of air capacities, pipe diameters, inclination angles and method of maintaining back pressure etc. on the line blowing process were investigated experimentally. The constant pressure valves used to maintain a back pressure showed satisfactory performance.

1. INTRODUCTION

In chemical tankers carrying noxious liquid substances in bulk, cargo usually remains in cargo piping and pumping arrangement or on the surface of cargo tank after unloading the tank by cargo pumping system.

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* Received on October 31,1989
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These noxious liquid substances or contaminated water genarated during the tank cleaning, line washing and tank ballasting are discharged into the sea. To reduce the pollution from ship, there is a need to minimize the remaining cargo and the discharging quantity of noxious liquid substances.

A quantity of residue remaining in the tank's associated piping and the immediate vicinity of that tank's suction point and its test procedure are specified in Annex II of MARPOL 73/78 and the Standards for Procedures and Arrangements(P & A Standards). The ability of the system to strip residue from the cargo piping is determined by performing a onboard water test for every ship carrying category B or C substances. During the water test either the 10 m.long vertical riser pipe (10mp) or the constant pressure valve(CPV) set at 1 bar minimum would be installed to maintain a back pressure of not less than 1 bar at the cargo tank's unloading manifold. Development of the practical CPV is required to perform the onboard water test efficiently.

For these purposes measures and methods on minimizing the quantity of residue in the piping in accordance with the test procedure set out in P & A Standards have been investigated. To remove residues from the piping system,

1) discharging operation with the cargo pump, and

2) discharging operation with the line blowing

were performed with the laboratory test arrangements under various operational conditions using water and air as working fluid. In this report, item 2) is described. Item 1) was discussed before[1].

The line blowing is the method to remove residues from piping by means of gas flow. Gas flow is generated by compressed gas supplied to the cargo piping when the manifold valve installed at the end of the cargo piping is opened quickly. Flow characteristics and quantity of residue in the pipeline, and the performance of the developed CPV have been obtained by the experiment. These results showed that line blowing is simple and effective method to strip water from the pipeline.

NOMENCLATURE

10mp= 10m. long vertical riser pipe
A,B,S= flow stage
CPV= constant pressure valve
d= diameter of orifice
D= inner diameter of the test section
P_1= air pressure in air storage tank
P_{10}= initial air pressure in air storage tank
P_2= pressure at middle point along the test section
P_3= back pressure
Q_0= remaining water volume in horizontal or inclined pipe
Q_1= volume of air storage tank
Q_{10}= volume of supplied water to the pipe
Q_H= volume of the pipe
R= remaining water ratio($=Q_0/Q_H$)

$T =$ time
$\beta = Q_1/Q_H$
$\eta =$ non-dimensional parameter (see eq. (2))
$\theta =$ inclination angle from the horizon
$\tau =$ full open/close time of the manifold valve (time required to open/close the manifold valve from zero to full opening or vice versa)

SUBSCRIPTS

$H =$ horizontal or inclined pipe
$P =$ back pressure maintained by a 10m. long vertical riser pipe
$V =$ back pressure maintained by a constant pressure valve

2. APPARATUS AND EXPERIMENTAL PROCEDURE

The apparatus used for this work was designed to demonstrate the fundamental characteristics and effectiveness of the line blowing method in accordance with the water test procedure set out in P & A Standards.

The detail of the test arrangement is shown schematically in Fig. 1. The test section consists of 11.2 m long steel or transparent plexiglass pipe supported by frame that can be pivoted between angles of ±2° from the horizon, the manifold valve V_1 (butterfly or ball valve) and the equipment to maintain a back pressure at the end of the horizontal or inclined pipe. They are same in bore diameter and

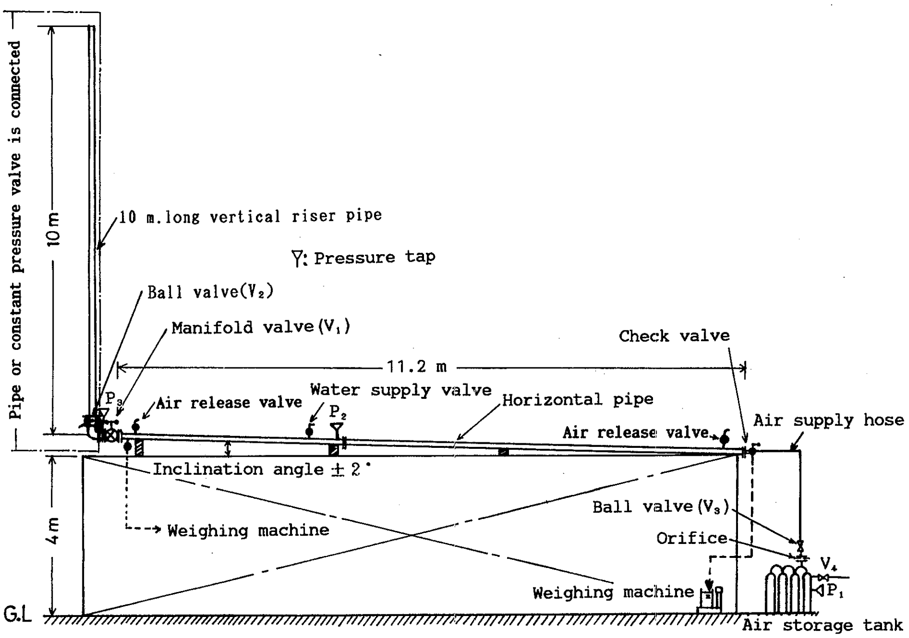


Fig. 1 Schematic diagram of experimental apparatus

connected in series. The internal diameters of the test section were 1, 2, 4 and 6in. Two different means were provided to maintain a back pressure. The first was a 10 m. long vinyl chloride or transparent plexiglass vertical riser pipe (10mp). The second was a constant pressure valve (CPV). The CPV will open at a gauge pressure of 1 kgf/cm^2 and the bore diameters were 4 and 6in.

To perform an experiment, at first, the pipeline was filled with water and the valve V_1 was closed. The valve V_1 was equipped either at the bottom of the 10mp or between the horizontal or inclined pipe end and the CPV. Then compressed air was supplied from the compressor through an air filter to the air storage tank at pressure of 1.5−9 Kgf/cm^2G. Volume of the air storage tank was varied by connecting the tanks (volume : 10ℓ, 20ℓ, 40ℓ, 70ℓx9) or changing the water level in the tank (volume : 1090ℓ). The valve V_4 was closed and the valve V_3 was opened. Air was supplied to the horizontal or inclined pipe from the air storage tank of fixed volume at certain initial pressure through the air supply hose (22m or 10m long and 1in. or 2in. ID) and the check valve.

The line blowing was started by opening the valve V_1. Motor operated manifold valve was opened/closed at constant speed. Full open/close time τ were 5.9, 10.2, 13.9, and 20 second. Water both in the horizontal or inclined pipe and the 10mp will be blown from the outlet of the pipeline to atmosphere by compressed air. The butterfly valve (4 and 6in. ID) and the ball valve (1 and 2in. ID) were used as the manifold valve. The line blowing was stopped by following four different stop modes, depending either on the location of the front of the air slug formed in the pipeline or the closing of the valve (manifold valve, quick closing ball valve V_2 or V_3).

Mode I : After the manifold valve is opened, no valve is operated during the period that water is blown from the outlet of the pipeline. The blowing will stop spontaneously owing to the decrease of air pressure.

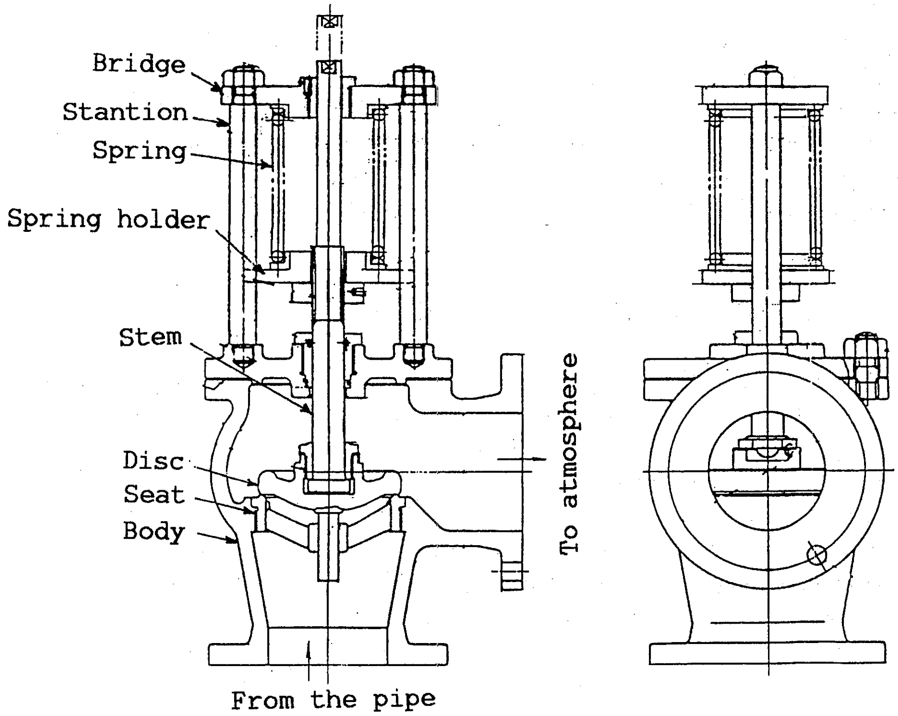
Mode II : The manifold valve begins to close at full close time after the front of the air slug has passed through the pipeline.

Mode III : Closing of ball valve V_2 or V_3 is done as quickly as possible after the front of the air slug has passed through the pipeline.

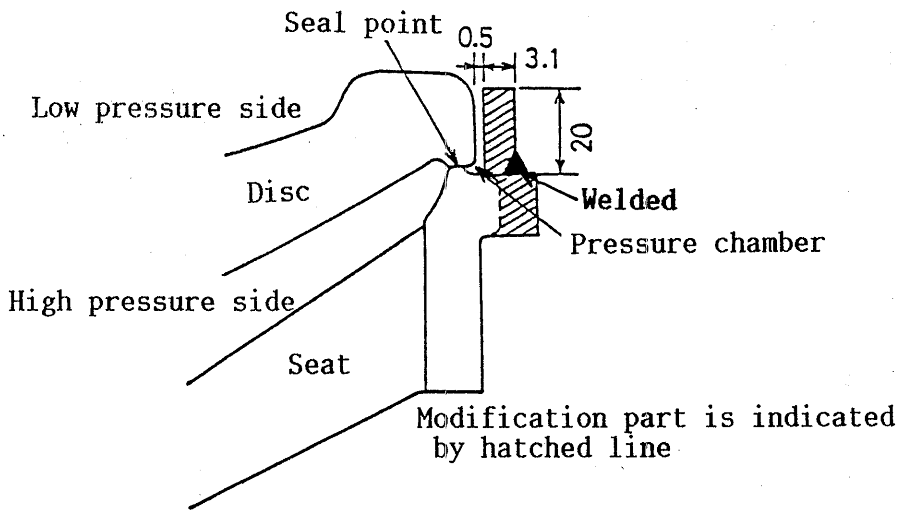
Mode IV : The ball valve V_2 or V_3 is quickly closed after the front of the air slug has passed through the horizontal or inclined pipe. This mode is same as the mode III for the test arrangement in which the back pressure is maintained by the CPV.

Experiments were carried out with the pipe for 0° and for upward inclination angles (plus) of 2° and 0.5° and for downward angles (minus) of 2° and 0.5° from the horizon. Additional tests were performed with partly filled water in the inclined pipe and with the orifices installed in the air supply hose.

Remained water in the inclined pipe befor the valve V_1 or V_2 was taken through the small diameter pipe branched at the entrance of the test section for plus inclination angle or at immediately upstream of the valve V_1 for negative inclination angle and weighed. Pressure taps were located at the air storage tank (P_1), middle point of the pipeline (P_2), the end of the pipeline, and between the CPV and the manifold



(a)



(b)

Fig. 2 (a) Constant pressure valve (b) Detail of seal point valve(P_3). Pressure P_3 means the back pressure.

The cross section of the constant pressure valve and the detail of its seat used in this work are shown in Fig. 2. This valve is based on the ordinary JIS 10K cast steel angle valve and made as a trial. The back pressure is maintained by the spring force acting upon between the disc and the seat, permitting water to discharge from the pipe. Direction of fluids flow is changed at right angle in the valve. The tripping point of the CPV was set at 1 Kgf/cm^2G.

3. DESCRIPTION OF THE LINE BLOWING PROCESS

To investigate the mechanism of water discharge from pipeline during the line blowing, observations of flow were made and the pressures were measured.

3. 1 Line Blowing Process

Fig. 3 shows the typical pressure variations with time at measured points and Photo. 1 shows air and water flow pattern blown from the exit of the 10mp. The experimental conditions were: diameter of the test section D=4in.,inclination angle of the pipe $\theta=+2°$, initial pressure in the air storage tank $P_{10}=5kgf/cm^2G$, volume of the air storage tank $Q_1=0.433m^3$, stop mode of the line blowing=mode I, full open time of the manifold valve $\tau=5.9$ sec.

As the manifold valve begins to open, air is blown into the test section.

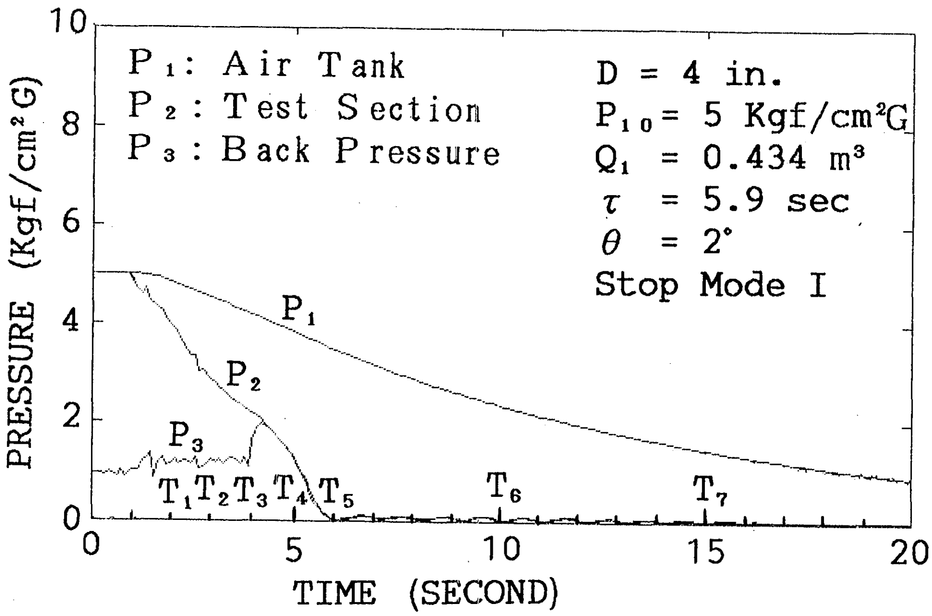


Fig. 3 Pressure diagram taken for the 10mP test arrangement

Photo. 1 Behaviors of water and air at the outlet of 10mp (top view)

Pressures P_1 and P_2 gradually decrease. Then air expands and single slug bubble is formed. The front of the bubble is rounded and leans over to upper side of the pipe. Water remains in the form of water layer with the gas passing above. Air pushes water column to atmospheric side, only water flows out(T_1-T_3). During this period, the back pressure P_3 increases slightly from initial value with small pressure fluctuation due to the motion of water column in the 10mp. Relative large pressure fluctuation was observed if the horizontal or inclined pipe was not completely filled with water before the start of experiment. The bubble slug is accelerated by the expansion of air. Back pressure P_3 increases significantly and the pressure P_2 approaches to P_3. After the front of the bubble slug passes through the inclined pipe, the air front travels the 10mp in the form of continuous single bubble slug, then the water in the 10mp is discharged and the amount of water in the 10mp decreases. Consequently, back pressure rapidly decreases(T_4). In the 10mp, air is formed into continuous single bubble, almost filling the pipe. The nose of the bubble is rounded. When the nose of bubble reached to the outlet of the pipeline, air-water mixture is violently blown out. The back pressure maintained by the water column in the 10mp decreases and approaches to atmospheric pressure(T_5). Where, as pressure in the air storage tank is sufficient to persist air flow, a certain quantity of water in the liquid film moves downstream of the pipe and is carried away in the form of droplets due to the forces exerted by the fast moving gas. Air flow with entrained liquid droplets is observed. Thickness of liquid film is rather thin(T_6). Air pressure in the air storage tank and air velocity in the pipeline decrease with time(T_7). The gas flow rate decreases further, the remaining water in the 10mp falls down to the bottom of the riser, accumulates, and forms a water slug, blocking the air passage, the water slug flows up in the 10mp. The line blowing will come to an end after repeating the process of fall-down and flow-up. Photo. 2 shows the flow pattern of each phase in the horizontal pipe.

In 6in. pipeline, wave appeared on the surface of the liquid layer at the back of the long bubble slug as the gas moves downstream of the horizontal or inclined pipe. The thickness of the liquid layer increases and approaches to the top of the pipe, finally bridges the pipe and blocks the gas flow. Pressure oscillations occured two to three times as a result of the bridging.

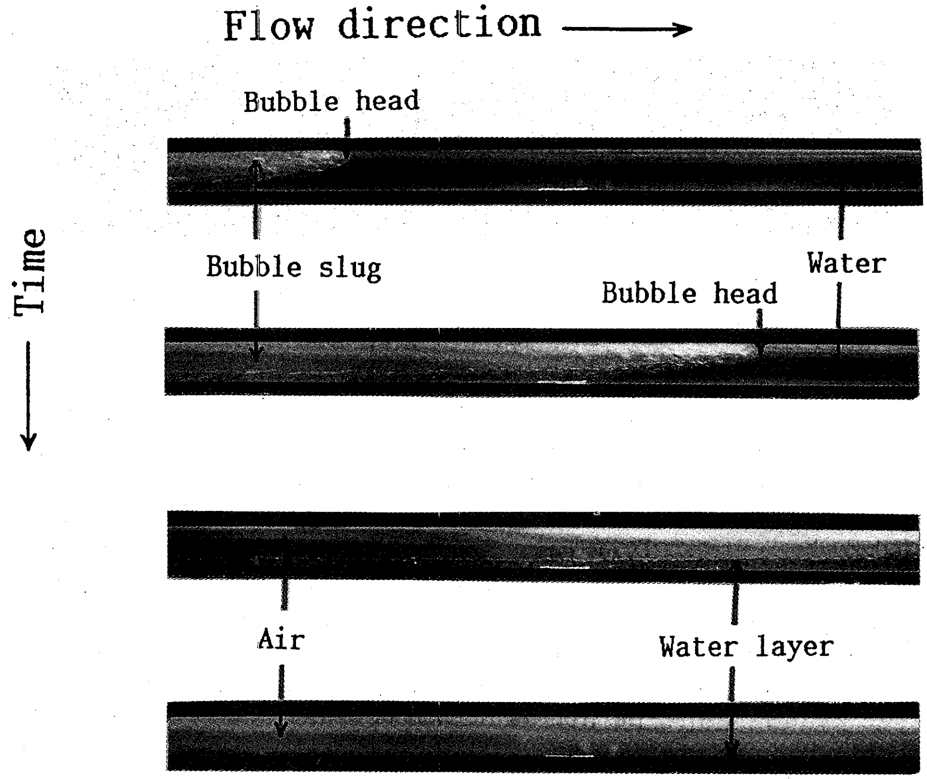


Photo. 2 Flow patterns of water and air in the horizontal pipe (D=4in.)

Fig. 4 shows the pressure diagram recorded during the process of the line blowing for the test arrangement where the back pressure is maintained by the CPV under typical experimental conditions (D=4in., P_{10}=5Kgf/cm^{2}G, Q_1=0.083m^3, θ=+2°, τ=5.9sec., stop mode=modeII). With opening the manifold valve, the CPV opens then air is blown into the inclined pipe, pressures P_1 and P_2 decrease. Air forms into continuous bubble slug on the upper side in the inclined pipe, water remains as the liquid layer on the lower side of the pipe. The single bubble slug travels downstream of the pipe and water is discharged into atmosphere. Pressures P_2 and P_3 decrease rapidly when the nose of the bubble slug reaches at the outlet of the pipeline. Air-water mixture is violently blown. Large pressure fluctuations due to chattering were measured in the case of 6in. CPV. Chattering was successfully reduced by the counter measure made at valve seat as shown in Fig 2. Further description appears in reference[2]. When pressures P_1, P_2, and P_3 become 1Kgf/cm^{2}G, the CPV is closed and the line blowing comes to an end. Behaviors of air and water are shown in Photo. 3. During the whole period from opening to closing of the CPV, pressure deviation from the preset back pressure occurs, depending on the magnitude of hydrodynamic losses due to the motion of fluids flow through the

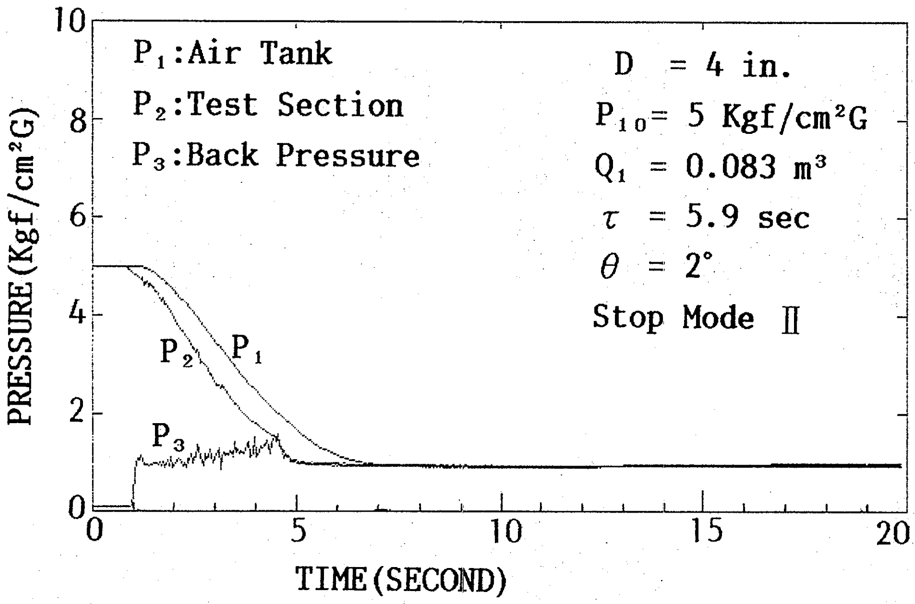


Fig. 4 Pressure diagram taken for the CPV test arrangement

valve, the greater the valve opening becomes, the higher the deviation is. However, the constancy of the back pressure is ensured both at the beginning and at the ending of the line blowing.

The noticeable difference of characteristics of the back pressure between two means are described as follows. The CPV maintains the back pressure of 1 Kgf/cm^2G minimum accompanying pressure fluctuation due to chattering but the 10mp cannot maintain the back pressure of 1 Kgf/cm^2G owing to water discharge from the 10mp after entering the bubble nose into the riser.

3. 2 Flow Observation

The process of line blowing can be classified into the following flow stages.

No discharge: No water discharges from the outlet of the pipeline when the pressure in the air storage tank is lower than the back pressure.

Flow stage B: The nose of the bubble slug moves downstream of the horizontal or inclined pipe. Water is blown from the outlet of the pipeline. Water in the riser remains full when the back pressure is provided by 10mp.

Flow stage S: The nose of the bubble slug moves downstream of the 10mp. Over full length of the horizontal or inclined pipe, water remains as the liquid layer with the gas passing above. After water is discharged, air-water mixture is blown from the outlet. This flow stage can not be observed when the back pressure is maintained by the CPV.

Flow stage A: This flow stage appears after the nose of the bubble slug reaches

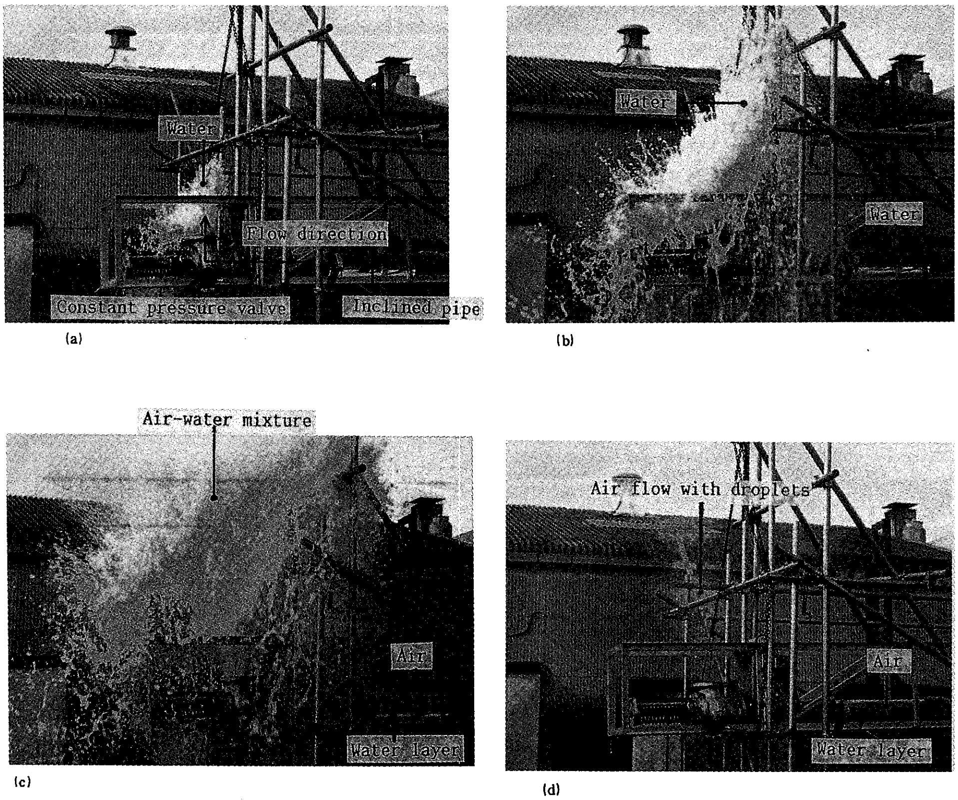


Photo. 3 Behaviors of water and air at the outlet of the CPV

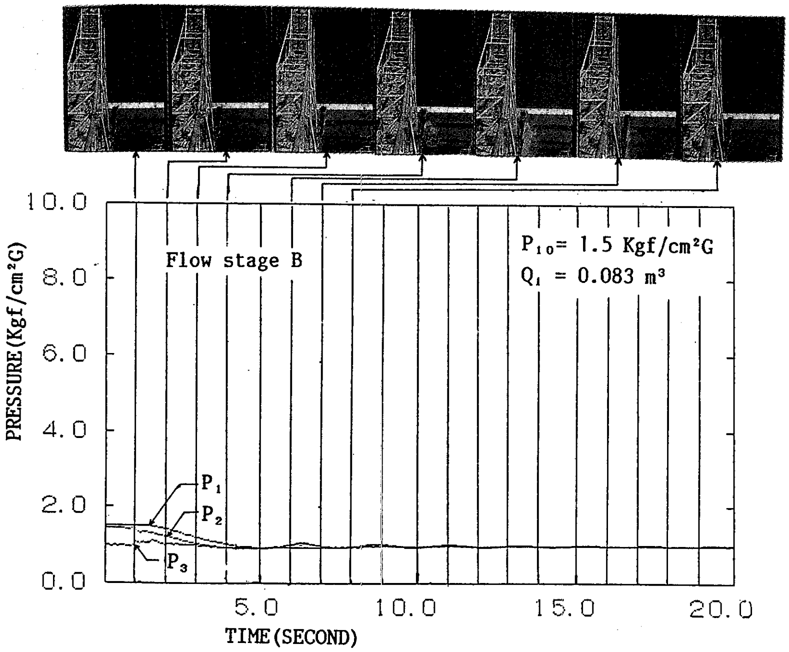
to the outlet of the pipeline. Air flow with small droplets is observed.

These flow stages are shown with pressure diagram in Photo. 4.

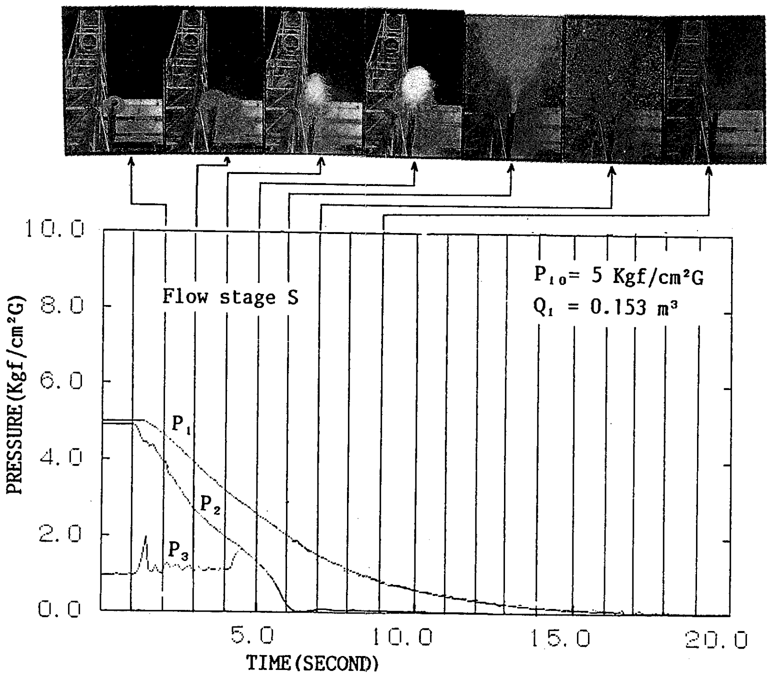
Following to the above description of the flow stages, the flow stages observed in the pipeline and at the outlet are shown in Figs. 5 and 6 with the coordinates of the initial air pressure in the air storage tank P_{10} and the volumetric ratio β of the air storage tank to the horizontal or inclined pipe, for different inclination angles and the diameters of the test section. The transition boundary lines of the flow stages are also shown in the figure. In order to occur the flow stage transition, high P_{10} requires for small β and large β requires for low P_{10}. The flow stage B takes place at lower P_{10} and β, the flow stage A occurs at higher P_{10} and β, the flow stage S appears in the region between flow stage B and flow satge A. Considering the difficulty in discriminating the flow stage by visual observation, there is insignificant difference in location and shape of the transition boundary line, and transition boundary line agrees well with each other. The effects of inclination angle and the diameter of the pipe on the flow stage is found small.

The flow stage S disappears when the back pressure is maintained by the CPV.

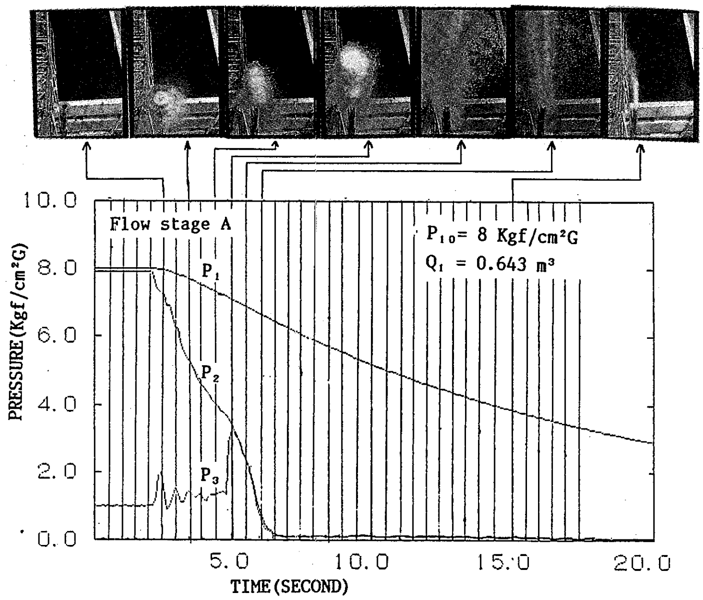
Another flow stage map is proposed in reference[3].


10.0
8.0
6.0
4.0
2.0
0.0
PRESSURE (Kgf/cm²G)
Flow stage B
P₁₀= 1.5 Kgf/cm²G
Q₁ = 0.083 m³
P₁
P₂
P₃
5.0
10.0
15.0
20.0
TIME (SECOND)

(a)


10.0
8.0
6.0
4.0
2.0
0.0
PRESSURE (Kgf/cm²G)
Flow stage S
P₁₀= 5 Kgf/cm²G
Q₁ = 0.153 m³
P₁
P₂
P₃
5.0
10.0
15.0
20.0
TIME (SECOND)

(b)



(c)

Photo. 4 Flow stage
(a) Flow stage B (b) Flow stage
(c) Flow stage A

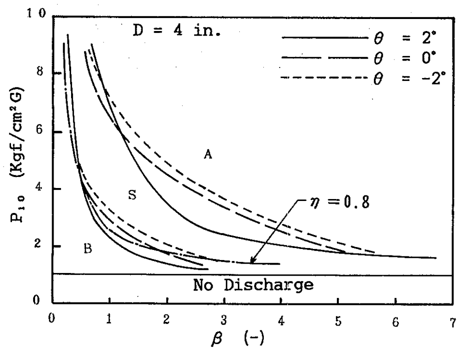


Fig. 5 Flow stage map for D=4in.

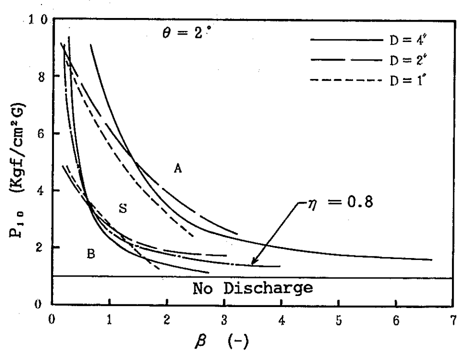


Fig. 6 Flow stage map for $\theta=+2°$

4. EXPERIMENTAL RESULTS

A series of experiments was made to find the effectiveness of the line blowing. The effects of several parameters on the amount of remaining water in horizontal or inclined pipe for two different means to maintain a back pressure are considered separately.

4. 1 Test Arrangement Connected with the 10m. Long Vertical Riser Pipe

4. 1. 1 Intitial Air Pressure and Volume of the Air Storage Tank

In Figs. 7 and 8, R_{HP} are plotted against initial air pressure in the air storage tank P_{10}, with the volume of the air storage tank Q_1 and inclination angle θ as parameter for stop mode II. It is clear that great deal of water is discharged from the pipe by the line blowing. R_{HP} decrease with P_{10} and Q_1, changing the trend with these parameters. As P_{10} and Q_1 increase, R_{HP} decrease for low values of P_{10} and Q_1, but R_{HP} decrease gradually for high values of P_{10} and Q_1. This means that increasing P_{10} and Q_1 are very effective to reduce the remaining water in the region of low P_{10} and Q_1. However, the effectiveness of the line blowing is reduced in the region of igh P_{10} and O_1. The data denoting the flow stage in Figs. 8 and 9 show that this trend is closely related to the flow stage, i.e.,water can be effectively discharged in the flow stage B compared with the flow stage S or A.

4. 1. 2 Inclination Angle of the Pipe

In Fig. 8, R_{HP} is plotted as a function of P_{10} for D=4in. The effect of inclination angle on R_{HP} is small at lower P_{10} and Q_1. However, R_{HP} is significantly affected by the inclination angle at high P_{10} and Q_1. Water can be effectively discharged for downward inclined pipe at high air flow rate because water moves and accumulates to the outlet rapidly owing to gravity forces.

4. 1. 3 Diameter of the Test Section

The test results are shown in Fig. 9 for the three pipes at inclination angle of +2°. The data for each pipe show similar trend. As β and P_{10} increase, R_{HP} decreases for every pipe. There is insignificant dependence of the diameter of the test section on R_{HP}.

4. 1. 4 Valve Operation

Fig.10 shows the effect of full open and full close time of manifold valve on R_{HP}. As the opening velocity of the manifold valve increases, the bubble slug is rapidly elongated and the dynamic effect to discharge water from the pipe outlet becomes large. As a result, great deal of water is blown and R_{HP} decreases. This can be applied exactly to the case of stop mode IV(quickly close the ball valve V_2) while the effect of full open time of the manifold valve on R_{HP} is small for stop mode I which spontaneously ends the line blowing.

4. 1. 5 Diameter of the Air Supply Hose

Air velocity in horizontal or inclined pipe would change as the diameter of the air supply hose, being higher the larger the diameter. It can be seen from Fig. 11 that R_{HP} is significantly affected by the orifice diameter. The feffect of the orifice diameter on R_{HP} is pronounced at high pressure and large volume of the air storage tank.

4. 2 Test Arrangement Connected with the Constant Pressure Valve

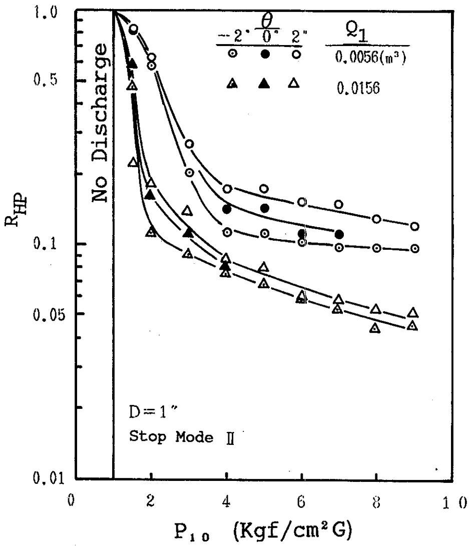


Fig. 7 Effect of air tank pressure on remaining water ratio (D=1in.)

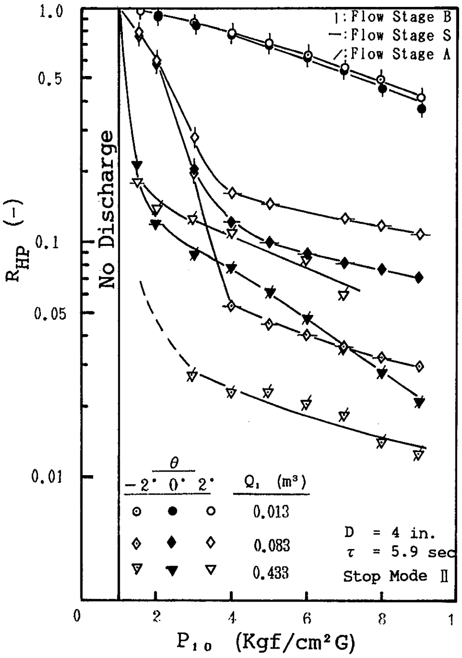


Fig. 8 Effect of air tank pressure on remaining water ratio (D=4in.)

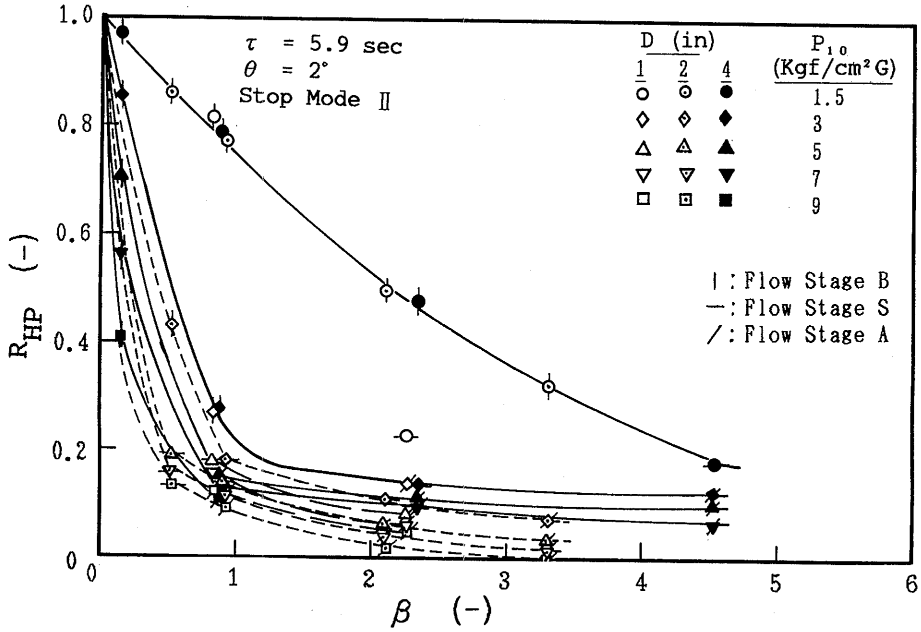


Fig. 9 Effects of air tank volume and pipe diameter on remaining water ratio

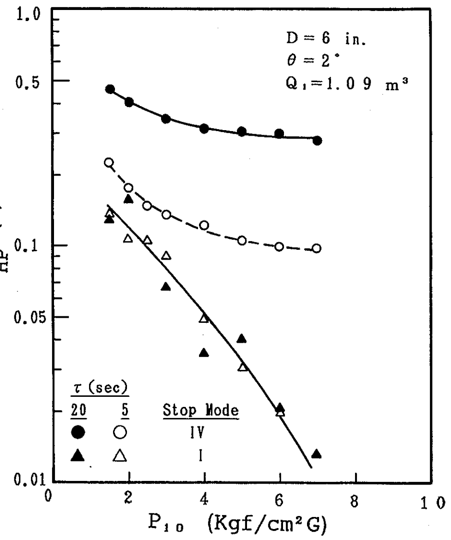


Fig. 10 Effect of valve operation mode on remaining water ratio

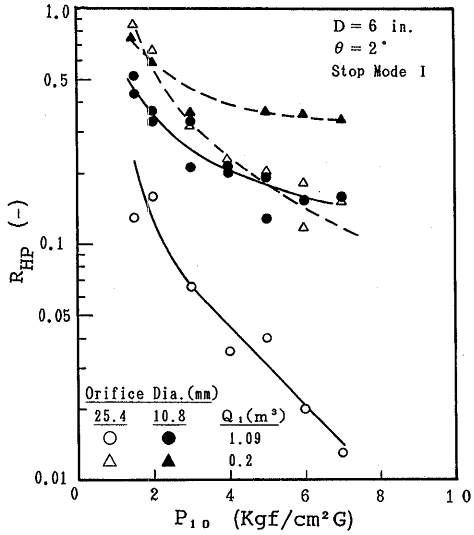


Fig. 11 Effect of diameter of air supply hose on remaining water ratio

In Fig. 12 experimental data of R_{HV} are plotted for the test arrangement which maintains the back pressure by the CPV. It can be seen that similar results to Fig. 8 are obtained. R_{HV} and R_{HP} for D=6 in. are shown in Fig. 13. For changing P_{10}, Q_1 and θ, insignificant effect of the mean to maintain the back pressure on R_H is noted. In Fig. 14, R_{HV} is plotted against P_{10}, with the ratio of the volume of supplied water to the inner vloume of the pipe Q_{10}/Q_H as parameter. When the small amount of water is supplied to the inclined pipe, the difference of R_{HV} between $Q_{10}/Q_H=1.0$ and $Q_{10}/Q_H \neq 1.0$ is significant at low air pressure. As the air pressure increases, the effect of the amount of initially supplied water on R_{HV} becomes small. This means that R_{HV} can not be reduced so much by reducing the amount of initially suppllied water. It is also noted that maximum R_{HV} is obtained for the data of $Q_{10}/Q_H=1.0$. In this experimental condition, fast moving water slug is formed and travels downstream of the pipe, liquid collides with the CPV which is equipped at the outlet of the pipe. As a result, complex high peak pressure variation was measured. The pressure peak is so high that the soundness of the plexiglass pipe is often lost. A further description can be found in reference[2].

5. DISCUSSIONS ON EXPERIMENTAL RESULTS

5. 1 Comparison of R_{HP} with R_{HV}

The data of R_H obtained from two different test arrangements for the same experimental condition are compared in Fig. 15, where P_{10} were 1.5−7.0 Kgf/cm²G. The back pressures maintained by the CPV and by the 10mp are same in static state

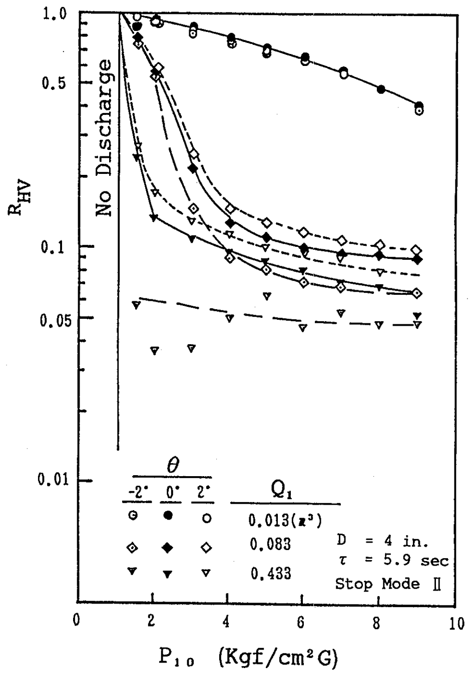


Fig. 12 Effect of air tank pressure on remaining water ratio for the CPV test arrangement

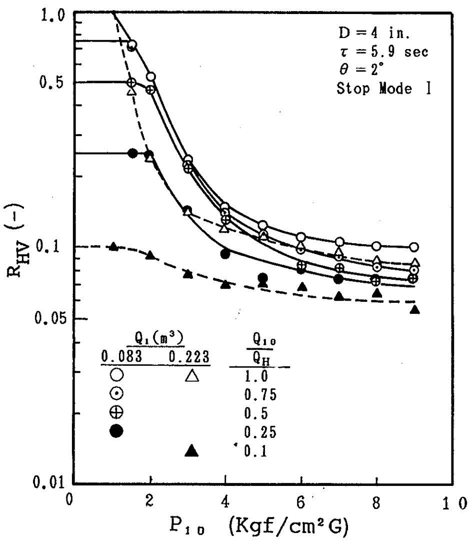


Fig. 14 Effect of initially supplied water ratio on remaining water ratio

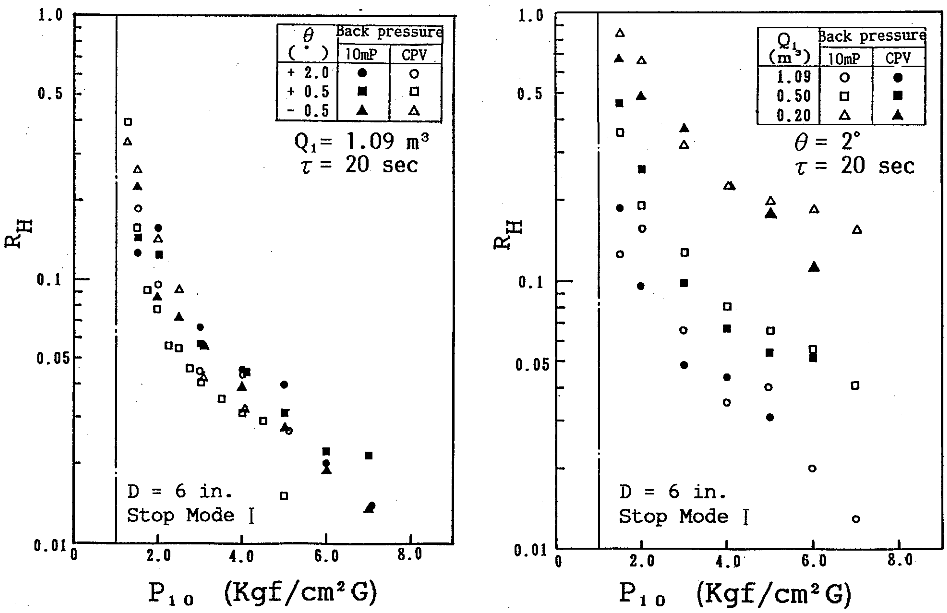


Fig. 13 Remaining water ratio for D=6in.

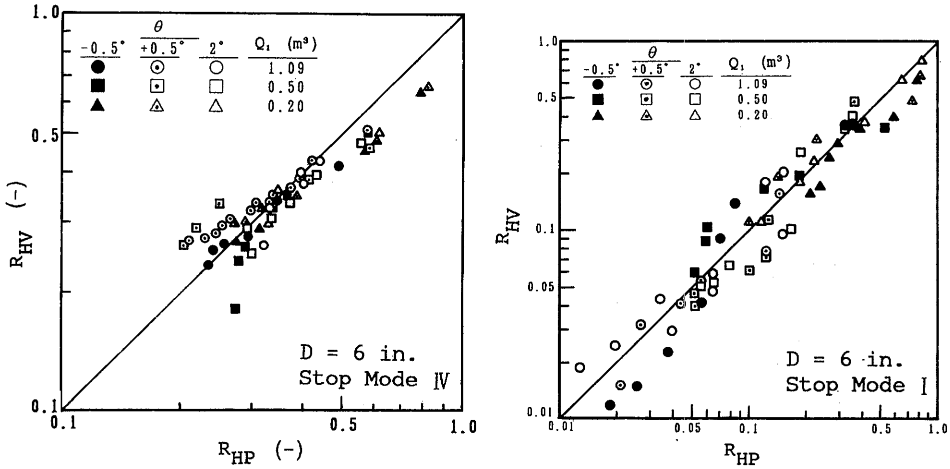


Fig. 15 Comparison of remaining water ratio for the 10mP test arrangement with that for the CPV test arrangement

but are not same in transient state. R_{HP} and R_{HV} agree well with each other over wide ranges of P_{10}, Q_1 and θ. This probably means that dynamic behavior of CPV and 10mp insignificantly effect on R_H, and we may say that the CPV used in this work have equivalent performance to 10mp.

5. 2 Correlation of R_H in Flow Stage B

Air at initial pressure P_{10} is supplied from air storage tank of volume Q_1 to horizontal pipe filled with water. It is assumed that the back pressure is maintained at initial pressure during the process of the line blowing in flow stage B and the air is expanded isothermally following to the ideal gas law. Then air volume blown into the horizontal pipe is $Q_1(P_{10}+1)/(P_3+1)-Q_1$. If water in the horizontal or inclined pipe is displaced by this volume of the air and the same volume of the water as the volume of the air is discharged from the pipe outlet, remaining volume of water in the horizontal or inclined pipe Q_0 may be expressed as

$$Q_0=Q_H-Q_1[(P_{10}+1)/(P_3+1)-1] \quad (1)$$

Then we get

$$R_H=Q_0/Q_H=1-\eta \quad (2)$$

where $\eta=Q_1[(P_{10}+1)/(P_3+1)-1]/Q_H$

This parameter η denotes the non-dimensional available air quantity of the air storage tank for the line blowing. Equation (2) was compared with experimental results by plotting R_H against η for various parameter in Fig. 16. In these comparison, the back pressure P_3 was taken as 1.0Kgf/cm²G. These data cover a wide variation of P_{10}, Q_1, Q_H, θ and τ, and the agreement with equation (2) is satisfactory

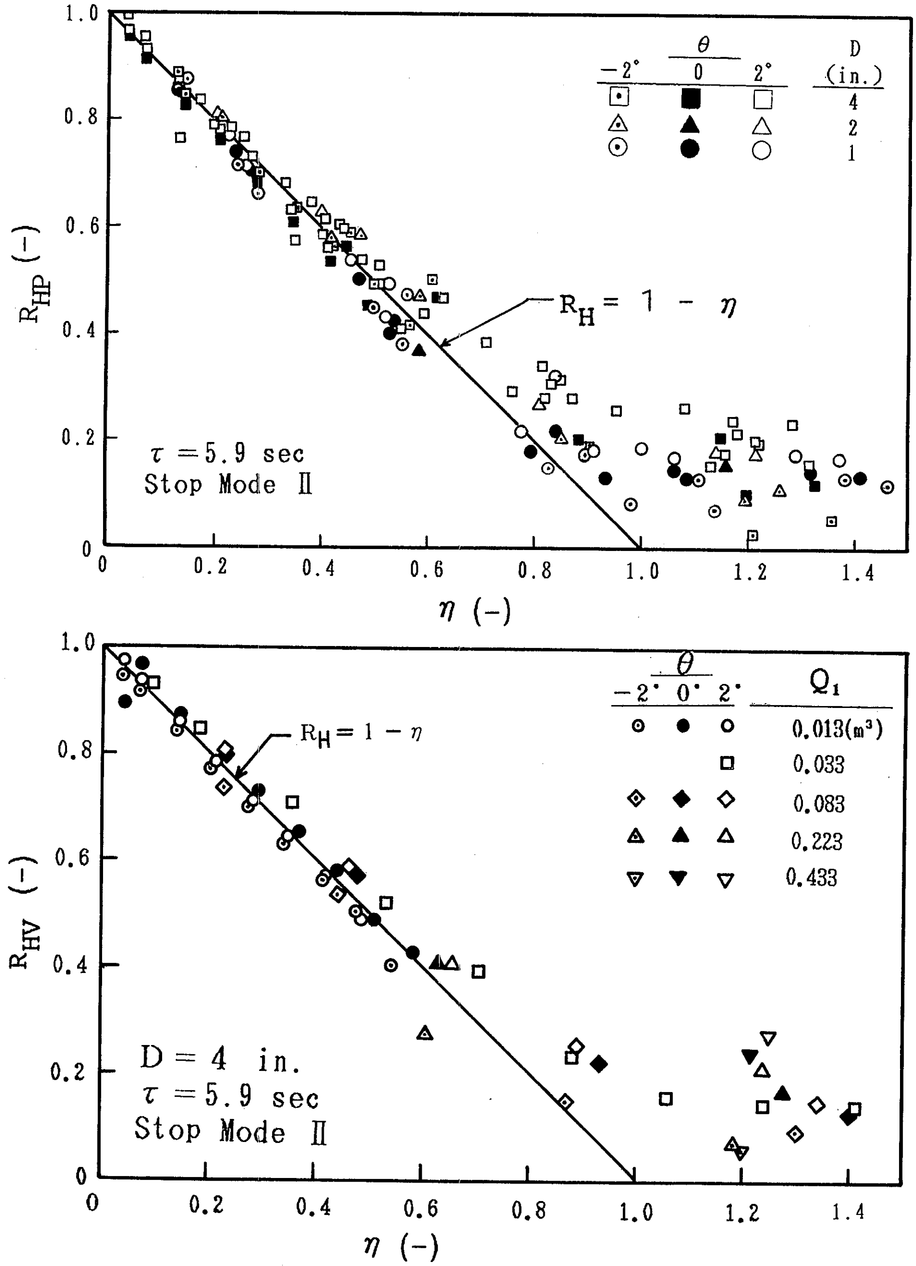


Fig. 16 Remaining water ratio against available air quantity

except for tfhe region of small R_{HP}. In the region satisfactorily expressed by equation (2), idealized model can be applied. Water is displaced by air blown into the horizontal pipe and air is used most effectively. When $_G$ is greater than about 0.8, dynamic effect of water and air flow can not be neglected, data are poorly correlated.

5. 3 Flow Stage B-to-S Transition Boundary

Water can be effectively discharged in the flow stage B compared with the flow stage S or A as described in 4.1.1. Several values of η are substituted in equation (2) to obtain the relation between β and P_{10} for comparison with the data of B-to-S flow transition boundaries. This comparison is made and fairly good agreement is obtained by $\eta = 0.8$ in Figs. 6 and 7. Consequently, R_H can be expressed by equation (2) in the flow stage B and B-to-S flow transition boundaries can be given by $\eta = 0.8$. From these results, the criteria of P_{10}, Q_1 and P_3 to discharge water effectively will be obtained.

6. CONCLUSIONS

1. Visualization studies of the line blowing have led to a better understanding of the processes of water discharge from the pipeline.
2. The influence of pipe inclination angle, pipe diameter, pressure and volume of the air storage tank, the valve operation and method to maintain back pressure on R_H have been described.
3. R_H can be calculated with good accuracy for flow stage B.
4. The constant pressure valve used in this work and the 10 m. long vertical riser pipe have equivalent preformance on R_H in spite of the difference of the value of the back pressure after the bubble nose enter the riser or inertial force by water column in transient state between the means to maintain back pressure.
5. The maximum R_H is obtained for the data of $Q_{10}/Q_H = 1.0$.
6. High peak pressure variation was measured in the experiment for $Q_{10}/Q_H \fallingdotseq 1.0$.
7. More work is necessary on analytical confirmation of the effectiveness of the line blowing method.

ACKNOWLEDGMENT

A part of this work was performed as the research program of the Shipbuilding Research Association of Japan and was published in Proc. Tenth Int. Symp. on the Transport of Dangerous Goods by Sea and Inland Waterways, Hamburg, p.278-287 (1989).

The authors would like to thank Mr. H. Miwa of Mitsumoto Valve Manufacturing Company for helpful discussions in designing the constant pressure valve.

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