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TESTS ON THE HYDRAULICS AND PNEUMATICS OF HOUSE PLUMBING

PART II

BY

HAROLD E. BABBITT

1867

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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PROFESSOR OF SANITARY ENGINEERING

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TESTS ON THE HYDRAULICS AND PNEUMATICS OF HOUSE PLUMBING

PART II

I. INTRODUCTION

1. *Purpose and Scope.*—The drainage pipes of a plumbing system may present a serious menace to the health of the occupants of a building because, through a direct connection with a sewer, foul gases, vermin, or even sewage may enter the building. Gases and vermin can be excluded by means of water-sealed traps. Air pressures, either above or below atmospheric, in the drainage pipes may remove water from the traps, thus breaking the protecting seal. It is desirable, therefore, to design drainage pipes so as to minimize the danger of seal breakage in traps resulting from air pressures in the pipes. These pressures may be either greater or less than atmospheric pressure.

Among the purposes of these tests was the discovery of a method of design or of devices to minimize the air pressures produced or to minimize their effects on trap seals. The tests reported herein include a demonstration of the relative effectiveness of various types of traps to resist seal rupture through siphonage, self-siphonage, and back pressure; a study of the most effective type of connection at the base of a stack; and a series of tests to determine the effectiveness of by-pass venting. A report of a test on the drainage pipes of a tall building under construction is also included.

A program of tests on the water supply pipes and appurtenances in plumbing systems has been commenced, and the results of some of these tests are also included in this report. These tests include a study of the rate of flow of water through commercial faucets; a study of the flow of water and of temperature control in batteries of shower baths; and a study of the effectiveness of various types of shower mixing valves in controlling the temperature of the water. Tests on water supply equipment are being made with a view towards developing better methods for the design of water supply pipes and in order to determine the relative effectiveness of valves, control devices, and other appurtenances.

2. *Previous Investigations.*—Tests on plumbing were first made at the University of Illinois in 1910. In 1919 a comprehensive series of tests on the drainage pipes of a plumbing system was begun. The results of the tests made between 1919 and 1924 were published in

Bulletin No. 143 of the Engineering Experiment Station, entitled "The Hydraulics and Pneumatics of House Plumbing." A comprehensive series of tests on plumbing has been made at the United States Bureau of Standards. The results of these tests are reported in a pamphlet entitled "Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings." This pamphlet is the latest published report of the Sub-committee on Plumbing of the Building Code Committee of the United States Department of Commerce. The report was published on July 3, 1923. The investigations at the United States Bureau of Standards and at the University of Illinois cover many similar problems.

3. *Acknowledgments.*—Since June, 1925, the research in plumbing has been conducted as a coöperative investigation under an agreement with the ILLINOIS MASTER PLUMBERS' ASSOCIATION. The Champaign and Urbana chapter of this Association donated labor and materials during the early period of the tests, and the Springfield, Illinois, chapter aided in the tests on the plumbing of the Ridgley Farmers State Bank Building in Springfield, Illinois.

The research work was under the direction of the author. Much of the hydraulic laboratory work during the year ending June, 1926, was performed by A. G. DIXON, who collaborated in the preparation of reports made to the Illinois Master Plumbers' Association. Mr. Dixon spent full time on this work until June 1, 1926, when he resigned and was replaced by Mr. A. E. PERRET who performed most of the hydraulic laboratory work until May, 1927.

The investigation has been a part of the regular work of the Engineering Experiment Station of the University of Illinois, of which Dean M. S. KETCHUM is the director, and of the Department of Civil Engineering, of which Prof. W. C. HUNTINGTON is the head.

II. TESTS OF TRAP SEALS

4. *Pressures.*—Pressures in the drainage pipes of plumbing systems were observed by means of U-tubes or traps arranged somewhat as is shown in Fig. 1. The maximum distance that the surface of the water was seen to move in the glass tube was taken as a measure of the air pressure exerted in the pipe to which the trap was attached. The distance that the surface of the water was observed to move in the trap was doubled, with proper correction for the differences of volumes of the two legs of the trap, to obtain the distance between the surfaces of the liquid in the two legs of the trap.

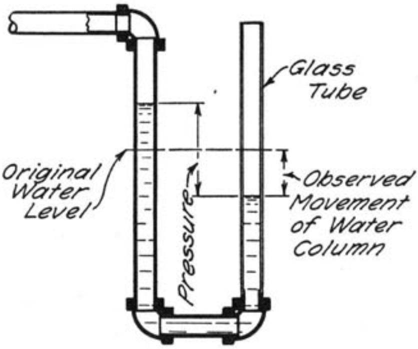


FIG. 1. PIEZOMETER FOR MEASURING AIR PRESSURES IN DRAINAGE PIPES

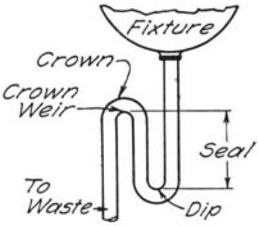


FIG. 2. PARTS OF A TRAP

The accuracy of this method of measuring pressures is discussed in University of Illinois Engineering Experiment Station Bulletin No. 143. The method was used in measuring all air pressures in plumbing systems. Although the movement of the water in the trap may not show the exact air pressure in the pipe it does show the phenomenon which it is most desired to control; i. e., the effect of air pressures on water in traps.

5. *Relation Between Depth of Seal and Strength of Seal of a Trap.*—It is desirable to know the relation between the depth of seal and the strength of seal of a trap in order to make possible a comparison of test data on different kinds of traps with different depths of seal. Knowledge of the relation between depth and strength of seal would make possible a reduction in the number of observations necessary for a comparison of various types of traps with different depths of seals.

The depth of the seal of a trap is defined as the vertical distance between the crown weir and the dip of the trap. This distance is

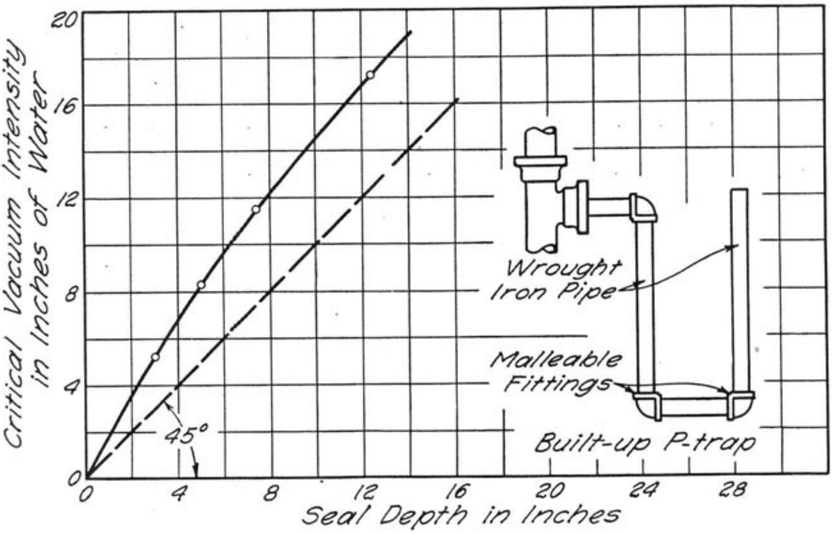


FIG. 3. SEAL STRENGTH IN TERMS OF SEAL DEPTH FOR A 1½-IN. P TRAP BUILT UP WITH THREADED FITTINGS

illustrated in Fig. 2. The strength of the seal of a trap is expressed in terms of the pressure necessary to depress the water sufficiently in one leg of the trap to permit air to pass the dip of the trap. If the movement of the water were very slow, and ceased when the surface of the water in one leg of the trap reached the dip of the trap, as shown in Fig. 2, the pressure necessary to force air under the dip would correspond to the height of the unbalanced water column, which is the same as the depth of the trap seal. In view of the rapid movement of the water in a trap it is evident that the distance between the crown weir and the dip of the trap and the depth corresponding to the strength of the seal cannot be equal as some of the pressure energy must be consumed in putting the water in the trap into motion.

Tests to determine the relation between the depth and strength of seal of traps were made by constructing P traps of threaded fittings, as shown in Fig. 3, with different depths of seal. The intensity of vacuum necessary to break the seal of each trap was determined. The results of one series of tests are plotted in Fig. 3. If it were not for the inertia of water in the trap, the relation between the depth of seal and the intensity of vacuum would be a straight line passing through the origin and making an angle of 45 deg. with either axis. Energy is required to overcome the

TABLE 1

INTENSITY OF SIPHONAGE REQUIRED TO BREAK TRAP SEAL

Kind of Trap	Diameter of Inlet and Outlet in.	Depth of Seal in.	Trap Capacity cu. cm.	Seal Volume cu. cm.	Intensity of Vacuum in Feet of Water Required to Break the Trap Seal, After the Number of Applications Shown.							
					Observed Intensities				Intensities Computed on Basis of 2-in. Seal			
					Number of Applications of Siphonage Without Seal Renewal				Number of Applications of Siphonage Without Seal Renewal			
					1	5	10	15	1	5	10	15
Lead P	2	1 9/16	398	184	0.42	....	....	....	0.54	....	....	....
Lead P	1½	2⅛	275	82	0.52	0.36	0.29	0.26	0.49	0.34	0.27	0.24
Lead P	1¼	2⅛	174	55	0.36	....	....	....	0.34	....	....	....
Lead S	2	2¼	480	186	0.52	....	....	....	0.46	....	....	....
Lead S	1½	2⅜	243	84	0.50	....	....	....	0.42	....	....	....
Lead S	1¼	2⅜	170	56	0.38	....	....	....	0.32	....	....	....
Lead Bag	2	2¾	532	188	0.66	....	....	....	0.48	....	....	....
Lead Bag	1½	2	236	84	0.48	....	....	....	0.48	....	....	....
Lead Bag	1¼	2¼	172	54	0.44	....	....	....	0.39	....	....	....
Drum (Inlet and Outlet at 180°)	1½	1½	935	530	2.50	0.71	0.53	....	3.33	0.95	0.53	....
Drum (Inlet and Outlet at 90°)	1½	3¼	1234	520	4.50	....	....	....	2.77	....	....	....
Lead Running	2	2⅝	520	173	0.70	....	....	....	0.53	....	....	....
Lead Running	1½	2⅛	235	84	0.44	....	....	....	0.41	....	....	....
Lead Running	1¼	2⅞	185	51	0.58	....	....	....	0.40	....	....	....
Non-siphon (Fig. 7A)	1¼	1¾	512	95	3.60	1.40	1.05	....	4.11	1.60	1.20	....
Non-siphon (Fig. 7B)	1¼	1⅛	160	56	0.40	0.15	....	....	0.71	0.27	....	....
Non-siphon (Fig. 7B)	1½	1⅜	129	43	0.40	0.21	....	....	0.58	0.30	....	....
Non-siphon (Fig. 7C)	1	7¼	944	208	5.20	2.67	1.82	....	1.43	0.71	0.30	....
Non-siphon Bulb P	1½	4¾	626	83	3.90	0.94	....	....	1.64	0.27	....	....
Built-up P	1½	7⅜	774	209	1.10	0.81	....	....	0.30	0.22	....	....
Built-up P	1½	2⅞	477	210	0.50	0.29	....	....	0.35	0.20	0.17	....
Built-up P	1½	12⅜	1140	210	1.66	0.93	0.80	....	0.27	0.15	0.13	....
Built-up P	1½	5	628	209	0.80	....	....	....	0.32	....	....	....

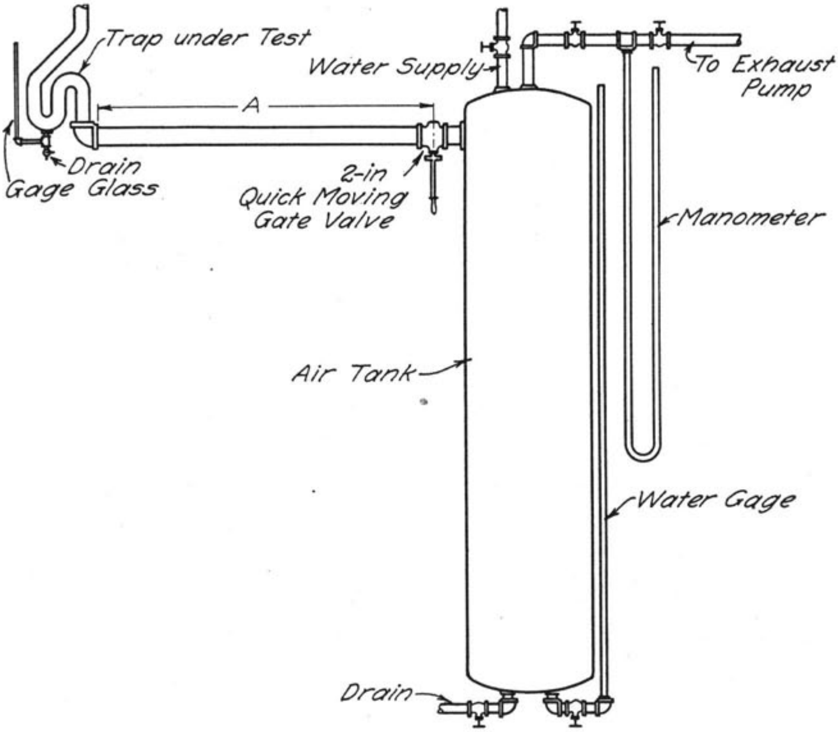


FIG. 4. APPARATUS USED FOR TESTS ON SIPHONAGE

inertia of the water in the trap. Hence the line showing the actual relation between intensity of vacuum and depth of seal is seen to lie above this 45-deg. line. Although this is not a straight line, the results of many tests, such as are illustrated in Fig. 3, show that it is sufficiently accurate for all purposes to assume the relation to be nearly a straight line in subsequent tests within the range of trap sizes used. The greatest difference between the pressures computed on the assumption of straight line variation and the observed pressures is less than 10 per cent, when the depth of seal is less than 7 inches, as shown in Fig. 3. The straight line was assumed to pass through the origin and the point representing the highest observed pressure.

6. *Comparison of Ability of Traps to Resist Siphonage.*—Among the desirable features of a trap are ability to resist breakage of the seal, a tendency to avoid clogging, protection of the seal against evaporation, etc. The seal of the trap can be broken by siphonage,

back pressure, or self-siphonage. The most desirable form of trap is, therefore, one that will most successfully resist seal breakage from all of these causes. A series of tests was conducted to determine the intensity of each of these forces required to break the seals of various types of traps. The types of traps tested are listed in Table 1.

The apparatus used for the siphonage tests is shown in Fig. 4. In the use of this apparatus the trap to be tested was set up as shown in the figure and the volume of water necessary to cover the dip of the trap was determined. The valve shown between the trap and the air tank is a 2-in. quick-moving gate valve. Water was poured into the trap to fill the seal, the overflow falling into the air tank through the open quick-moving valve. This valve was then closed and water run into the air tank until the volume of air remaining in the tank represented the conditions desired for the particular test being conducted. All openings to the air tank were then closed, and the air exhaust pump was operated until the desired intensity of vacuum was attained, as shown by the manometer tube at the extreme right of the figure.

As soon as the desired conditions had been secured the quick-moving valve was jerked open smartly. This subjected the water in the trap to a vacuum of the same intensity as that in the tank and resulted in some of the water being drawn from the trap. When motion following the opening of the quick-moving valve had ceased, the volume of water remaining in the trap was measured. If the remaining volume of water was insufficient to cover the dip of the trap the seal was reported to have been broken.

At the beginning of the tests it was discovered that the volume of air remaining in the tank when the partial vacuum was created had a marked effect on the intensity of vacuum necessary to break the trap seal. The intensity of vacuum necessary to break the seal of a trap was found to decrease as the volume of air in the air tank was increased up to a certain point. Beyond this point an increase in the volume of air in the air tank had no effect on the intensity of vacuum necessary to break the seal of the trap. This condition is shown in Fig. 5.

The volume of air in the air tank corresponding to this critical point was called the *critical volume* for that trap. In all tests reported herein the volume of air in the air tank was greater than the critical volume for the particular trap tested.

In tests on traps made for comparison of the strength of trap seals it is essential that the volume of air in the air tank be above the

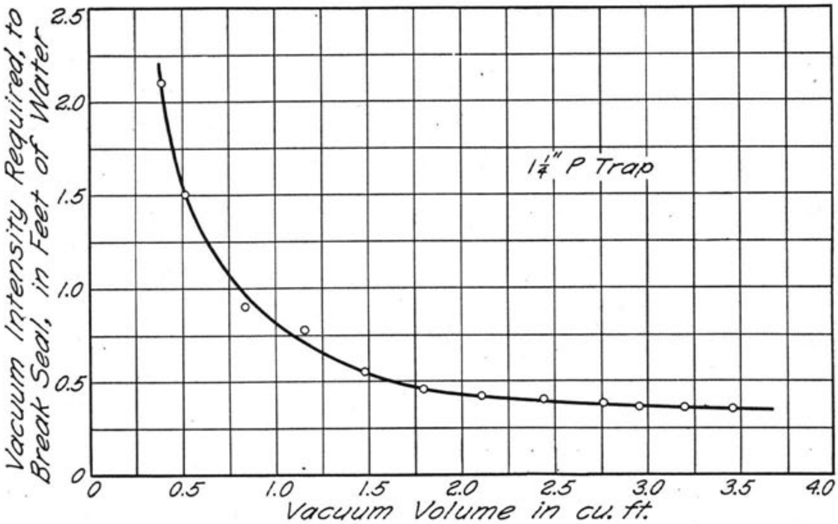


FIG. 5. EFFECT OF CRITICAL VOLUME IN TRAP SIPHONAGE TESTS

critical volume. The volume of air in plumbing systems is usually above the critical volume. When an air chamber with a volume below the critical volume is used in testing the effect of the intensities of vacuums on different traps the results will be of no general significance.

The intensity of vacuum necessary to break the seal of a trap was found by trial. The trial was made by increasing or decreasing the intensity of vacuum until the seal of the trap was just broken or just failed to be broken, according to whether the intensity was being increased or decreased. The tests were repeated a number of times, and the results were found to check closely and consistently. The results of the tests are shown inTable 1.

A comparison of the strengths of seals of various types of traps is of more value than a comparison of the strengths of seals of individual traps. A factor of importance in affecting the intensity of vacuum required to break the seal of a trap is the depth of the seal of the trap. It would be incorrect to conclude that a greater intensity of vacuum is required to rupture the seal in all running traps than is required in all bag traps because a greater intensity of vacuum was required by test to break the seal of a running trap with a 4-in. depth of seal than was required to break the seal of a bag trap with a 2-in. depth of seal. In comparing the intensities of vacuum required to break the seals of different types of traps it is necessary, therefore, to re-

TABLE 2
RELATIVE STRENGTH OF TRAPS TO RESIST SIPHONAGE

Kind of Trap	Size of Trap, in.	Relative Intensity of Resistance to a Single Application of Siphonage	Relative Intensity of Resistance to 12 Repeated Applications of Siphonage Without Restoration of Trap Seal
Non-siphon (hair pin) Fig. 7A	1¼	100	100
Drum (inlet and outlet @ 180°)	1½	81	59
Drum (inlet and outlet @ 90°)	1½	67	....
Non-siphon. Bulb P	1½	40	17
Non-siphon (Fig. 7C)	1	35	44
Non-siphon (Fig. 7B)	1¼	18	17
Non-siphon (Fig. 7B)	1½	13	29
Lead P	2	13	....
Lead Running	2	13	....
Lead P	1½	12	21
Lead Bag	2	11	....
Lead Bag	1½	11	....
Lead S	2	11	....
Lead S	1½	10	....
Lead Running	1½	10	....
Lead Running	1¼	9.7	....
Lead Bag	1¼	9.5	....
Built-up	1½*	8.5	12
Lead P	1¼	8.3	....
Built-up P	1½*	7.8	....
Lead S	1¼	7.8	....
Built-up P	1½*	7.3	14
Built-up P	1½*	6.6	9.4

*Very short waste line; shorter than used on lead P traps.

duce all results to a common depth of seal, if this is possible. If it were not possible, it would be necessary, in comparing different styles of traps, to test a number of traps of each style, no two traps in any one style having the same depth of seal.

The relation between the strength and the depth of a trap seal was found, as explained in Section 5, to be a straight line. It is, therefore, possible to reduce all observed intensities of vacuums for any depth of seal to a common ''standard'' depth. The depth assumed for this purpose was 2 inches, and all results have been reduced to this common depth, as shown in the last four columns of Table 1.

The relative strength of different types of traps to resist seal rupture by siphonage is shown in Table 2, in which the traps are arranged in order, with the most resistant at the top of the table. The conclusions reached from a study of the observations recorded in this table are:

(1) A non-siphon trap with tortuous passages required the greatest intensity of vacuum to break its seal; and a 1½-in. built-up P trap required the least intensity of vacuum to break its seal.

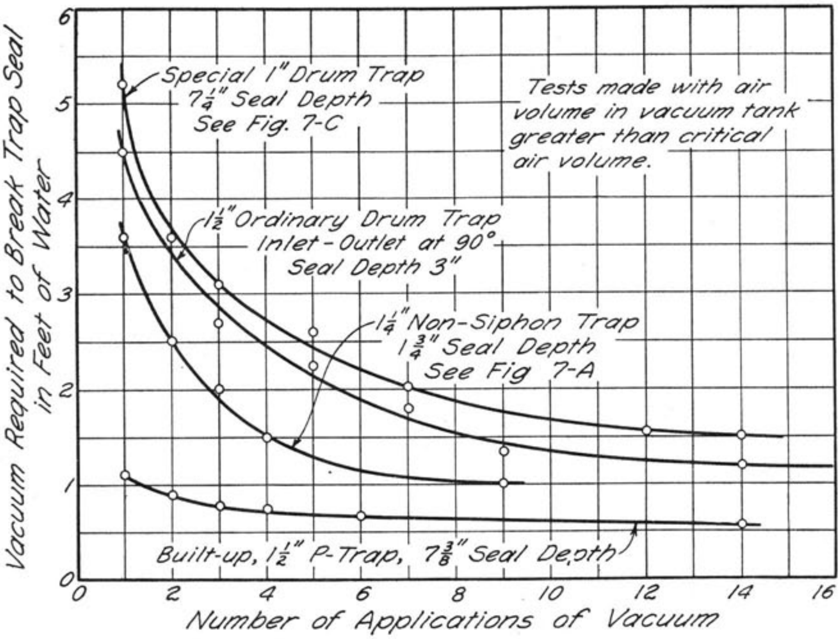
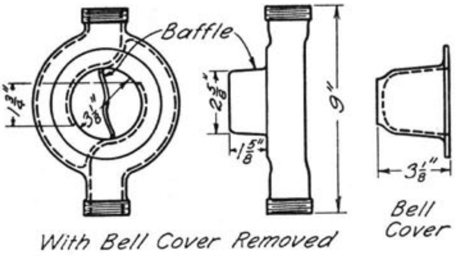


FIG. 6. STRENGTH OF TRAP SEALS TO RESIST REPEATED APPLICATIONS OF SIPHONAGE (VACUUM) WITHOUT REPLENISHMENT OF WATER IN TRAP SEAL

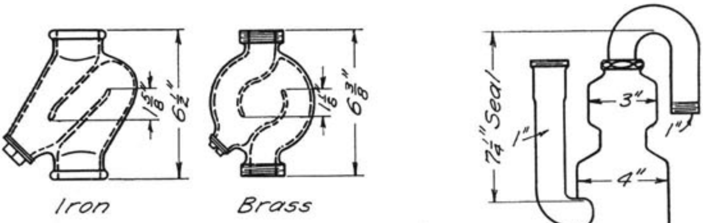
(2) There is less difference between the relative resistance of traps to repeated applications of siphonage than to a single application.

7. *Effect of Repeated Applications of Siphonage.*—In the ordinary plumbing system the trap on a fixture will be subjected to siphonage caused by the discharge of other fixtures many times between the times of discharge of its own fixture. The effect of the repetition of siphonage on a trap without renewal of water in the seal might be to break the seal with less intensity of siphonage than would be required by a single application of siphonage to the full seal of the trap.

Tests were made to determine the effect of repeated applications of siphonage by means of the apparatus shown in Fig. 4. The intensity of siphonage necessary to rupture a trap seal after a number of repetitions was determined by repeating, without replacing water in the seal, the application of some fixed intensity of siphonage a sufficient number of times to break the trap seal. If the seal was not broken after fourteen applications, the intensity of siphonage was increased, water was restored to the trap seal, and the higher siphonage was applied fourteen times, or a sufficient number to rupture the



(A)-Interior Baffle "Hair Pin" Trap



(B)- Interior S-Baffle Traps

(C)-Drum Trap

FIG. 7. SOME TYPES OF NON-SIPHON TRAPS TESTED BY REPEATED SIPHONAGE

trap seal. Not more than fourteen repetitions of pressure were used, as it was found, as shown by the curves in Fig. 6, that beyond about twelve repetitions, without renewal of the seal, the change in intensity of pressure necessary to rupture the seal was slight. In the study of any trap the intensity of siphonage was progressively increased until the intensity necessary to rupture the seal on the first application was reached.

The results of some of these tests are given in Table 3 and plotted in Fig. 6. The results are significant, and should have weight in the selection of traps from the viewpoint of seal strength. They show that a much smaller intensity of siphonage is required to break the seal of a trap after repeated applications than for one application only. In making a comparison of relative strengths of seal of different traps conclusions should be based on repeated tests without restoration of seal, and not upon a single application of siphonage to the full seal of the trap.

The results show that the difference of strength of seal in non-siphon and simple traps, respectively, is much less under repeated tests; that the seal in the best non-siphon trap can be broken with

TABLE 3

STRENGTH OF TRAP SEALS TO RESIST REPEATED APPLICATIONS OF SIPHONAGE WITHOUT REPLENISHMENT OF WATER IN TRAP SEAL

Type of Trap	Intensity of Vacuum in Feet of Water Required to Break the Seal													
	Number of Repetitions													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14 (estimated)
1¼-in. Non-siphon (Fig. 7A)	3.60	2.50	2.00	1.50	....	....	....	....	1.00	....	....	....	....	....
1¼-in. Non-siphon (Fig. 7B)	0.40	0.35	0.25	....	....	0.15	....	....	....	....	....	....	....	....
1½-in. Non-siphon (Fig. 7B)	0.40	0.30	....	....	....	0.20	....	....	....	0.15	....	....	....	....
1½-in. Lead P	0.49	0.44	0.39	....	0.34	....	0.29	....	....	....	....	....	....	0.24
1½-in. Drum, 3-in. Seal	4.5	3.6	2.7	....	2.25	....	1.8	....	1.35	....	....	....	....	1.2
Non-siphon (Fig. 7C)	5.2	3.6	3.1	....	2.6	....	2.04	....	....	....	....	1.53	....	1.5
Built-up P, 7⅜-in. Seal	1.10	0.88	0.77	....	....	0.66	....	....	....	....	....	....	....	0.55
Built-up P, 2⅞-in. Seal	0.50	0.45	0.40	0.35	....	....	....	0.30	....	....	....	....	....	0.25
Built-up P, 12⅜-in. Seal	1.66	1.33	....	1.16	....	....	....	1.00	....	....	....	....	....	0.84

only a little more than twice the intensity of siphonage required to break the seal of a simple trap; and that an ordinary drum trap is as effective a non-siphon trap as the best of the patented proprietary non-siphon traps.

8. *Comparison of Ability of Traps to Resist Back Pressure.*—The seal of a trap may be broken by back pressure expelling water from the trap either into or through the fixture into the room in which the fixture is located. The water which falls in the fixture will drop back into the trap to aid in restoring the seal. Only that water which is blown out of the fixture or retained in it is lost from the seal of the trap. The intensity of back pressure necessary to break the seal of a trap is dependent primarily, therefore, upon the distance between the dip of the trap and the opening into the fixture. It is dependent also upon the type of the fixture. Since these two factors have no relation to the type of trap, no conclusions of value can be drawn with reference to the relation between the type of a trap and the intensity of back pressure necessary to break its seal.

Because of the relation between siphonage and back pressure, and the symmetry of most traps, it seems safe to conclude that, if all water rising above the crown weir in the inlet pipe of a trap due to back pressure were removed as fast as it rose, the intensities of back pressure and of siphonage required to break the seal of a trap would be equal. This has no practical significance, however, except as indicating that a much greater intensity of back pressure is usually necessary to break the seal of a trap. It is evident that repetitions of back pressure, none of which remove water from the trap, will not be more effective in breaking a trap seal than a single application of the same back pressure.

9. *Comparison of Ability of Traps to Resist Self-siphonage.*—Self-siphonage occurs in a trap when water is discharged through the trap from the fixture to which the trap is connected. The combined effect of the inertia of the water passing through the trap, and the partial vacuum created by the falling water in the discharge pipe from the trap is to leave insufficient water to fill the trap seal or it may even leave the trap seal broken after the completion of a discharge. An important factor in the design of most fixtures and traps which counteracts the effects of self-siphonage upon traps is the construction of the fixture or waste pipe so as to retain an appreciable quantity of water, after the fixture discharge is completed, to drip into the trap and restore its seal.

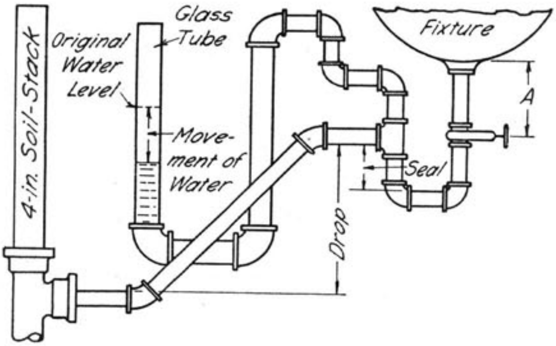


FIG. 8. APPARATUS USED FOR STUDYING FACTORS AFFECTING SELF-SIPHONAGE

The factors affecting self-siphonage have been reported in Bulletin No. 143. These factors can be summarized as follows:

(1) The resistance of a trap to self-siphonage is increased by impeding the flow of water through the trap.

(2) The resistance of a trap to self-siphonage varies with the depth of seal of the trap.

(3) The intensity of vacuum produced in a trap when water is discharging through it varies with the rate of discharge.

(4) The intensity of vacuum produced in a trap when water is discharging through it varies with the drop on the waste or discharge pipe.

(5) The intensity of vacuum produced in a trap by self-siphonage is independent of the length of vertical pipe between the trap and the fixture provided the rate of discharge remains unchanged.

(6) The destruction or weakening of the seal of the trap by self-siphonage can be prevented by venting, or by the design of the fixture.

The apparatus used in reaching these conclusions is shown in Fig. 8. This apparatus, and others which were used, were found to be unsatisfactory for the purpose of comparing the relative strengths of seals of different types of traps to resist rupture through self-siphonage because of the residual water which dripped from the fixture, the valve, and the walls of the waste pipe acting to restore the seal after the completion of the fixture discharge.

The type of apparatus finally used, and which was found to be satisfactory, is illustrated in Fig. 9. In making a test of a trap with

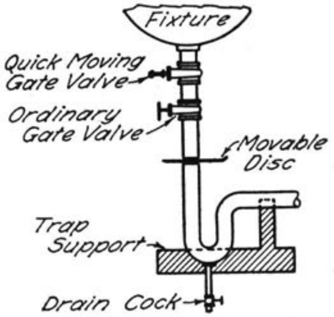


FIG. 9. APPARATUS USED TO DETERMINE RESISTANCE OF TRAPS TO SEAL BREAKAGE BY SELF-SIPHONAGE

this apparatus the trap to be tested was fixed in position as illustrated. The quick-moving gate valve was closed. The ordinary gate valve was set to deliver water at a predetermined rate. The fixture, which consisted of a conical galvanized iron tub, was filled with water to a level, which, in conjunction with the opening of the gate valve, determined the rate of discharge. The quick-moving gate valve was then opened with a swift motion. When the trap was seen to be running full a flat disc or plate was quickly inserted in the opening shown in the waste pipe at the same time that the quick-moving valve was closed. The disc was held close to the end of the upper pipe. Thus all drip was prevented from passing through the trap and the effect of siphonage on the trap was not interfered with. The amount of water remaining in the trap was then measured. This was seldom found to be exactly enough to seal the trap, it was either too much or too little. Each test was repeated at least five times without change of conditions. The average of the quantities of water remaining in the trap for any number of repetitions at the same rate of discharge was plotted against the rate of discharge thus locating a point on a diagram. Other rates of discharge were tried and points located in the same way. The points determined in this manner were then joined, as shown in Fig. 10. The rate of discharge at which the line thus plotted intersected the vertical line representing the volume of water necessary to seal the trap was recorded as the rate of discharge necessary to break the seal of the trap by self-siphonage under the conditions of the test. Various waste pipe arrangements were used in testing each valve. The results of the test are shown in Tables 4 and 4a, and some results are plotted in Fig. 10.

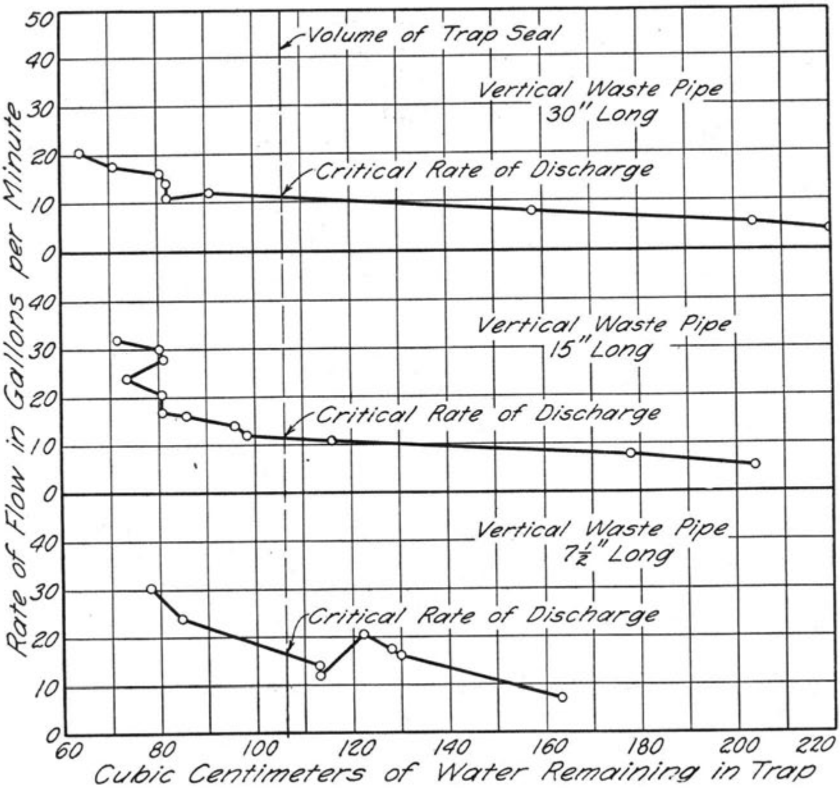


FIG. 10. TESTS ON SELF-SIPHONAGE OF A 1½-IN. BAG TRAP

It is concluded from these tests that

(1) The relative order of strength of seal to resist self-siphonage in standard lead traps is running, bag, P, and S, the running traps having the strongest seal.

(2) An increase in the length of either the vertical or the horizontal portion of the waste pipe, up to a certain limit, causes less water to be left in a trap after the discharge of the fixture to which it is attached. This renders easier the breaking of the trap seal by air pressure.

(3) The point at which an increase in the length of the waste pipe will not cause a decrease in the water left in the trap after the discharge of a fixture is reached when the friction becomes great enough to reduce the maximum flow which can pass through the trap. This condition is illustrated in runs 59 and 60 shown in Table 4.

TABLE 4
RESULTS OF SELF-SIPHONAGE TESTS
Standard Lead Traps

Type of Trap	Size of Trap and Waste Pipe in.	Length of Horizontal Waste Pipe in.	Length of Vertical Waste Pipe in.	Seal Volume cu. cm.	Critical Rate of Discharge gal. per min.	Run No.
P	2	0	0	220	64	1
P	2	0	17	220	32	2
P	2	0	30	220	26	3
P	2	53	0	220	38½	4
P	2	53	15	220	41½	5
P	2	53	30	220	39	6
P	1½	6	0	165	13½	7
P	1½	6	15	165	10	8
P	1½	6	30	165	11	9
P	1½	53	0	165	10½	10
P	1½	53	15	165	9	11
P	1½	53	30	165	8½	12
P	1¼	53	0	88	10	13
P	1¼	53	15	88	8	14
P	1¼	53	30	88	7	15
P	1¼	0	0	88	24	16
P	1¼	0	15	88	11	17
P	1¼	0	15	88	10	18
P	1¼	0	30	88	9	19
S	2	0	8½	198	53½	20
S	2	0	15	198	28	21
S	2	0	30	198	26½	22
S	1¼	0	5½	58	18	23
S	1¼	0	15	58	10	24
S	1¼	0	30	58	7	25
Bag	2	0	7½	188	58	26
Bag	2	0	15	188	36	27
Bag	2	0	30	188	33	28
Bag	1½	0	7½	106	20	29
Bag	1½	0	15	106	11½	30
Bag	1½	0	30	106	11	31
Bag	1¼	0	7½	44	56	32
Bag	1¼	0	15	44	25	33
Bag	1¼	0	30	44	13½	34
Running	2	0	30	204	44	66
Running	2	0	45	204	41	67
Running	2	0	60	204	33	65
Running	2	0	90	204	34	68
Running	1½	0	90	74	20	58
Running	1½	0	120	74	28*	59
Running	1½	0	150	74	28*	60
Running	1¼	0	30	52	35*	62
Running	1¼	0	45	52	36½	63
Running	1¼	0	60	52	31	61
Running	1¼	0	90	52	14	64

*This is the fastest rate at which water would pass through the trap. The seal of the trap was **not** broken at this rate.

(4) It is possible to select a size and type of trap which cannot lose its seal from self-siphonage if the rate of discharge from the fixture and the arrangement of the waste pipes are within the limits of those used in obtaining the results recorded in Table 4. For example, let it be desired to install a wash tray with a vertical drop of 30 in. in the waste pipe from the trap to the main waste. The rate of discharge from a wash tray is assumed to be equal to three fixture units, or 22.5 gallons per minute. From Table 4 it is seen that a greater rate of discharge than 22.5 gallons per minute is required to siphon any 2-in. trap with 30-in.

TABLE 4a
RESULTS OF SELF-SIPHONAGE TESTS
Non-siphon Traps*

Type of Trap	Size of Trap in.	Length of Waste Pipe in Inches		Seal Vacuum cu. cm.	Max. Rate of Discharge Which Would Pass Through the Trap gal. per min.	Run No.
		Horizontal	Vertical			
Drum Trap Outlet 90° from Inlet	1½	0	15	479	22	40
	1½	0	30	479	22	41
	1½	0	60	479	25	42
	1½	0	120	479	46	43
Centrifugal Drum Trap, Fig. 7c	1	0	15	234	8½	44
	1	0	30	234	4	45
	1	0	60	234	22	46
	1	0	120	234	25	47
Bulb Trap S Type	1½	0	0	77	41	48
	1½	0	15	77	48	49
	1½	0	30	77	50	50
	1½	0	60	77	50	51
	1½	0	120	77	50	52
	1½	120	0	89	30	53
Bottle Trap	1½	0	60	39	6½	54
	1½	0	120	39	4	55

*The maximum rate of discharge (up to 50 gal. per min.) which would flow through these traps was insufficient, in every case, to break the seal of the trap.

of vertical waste pipe. If the fixture were a kitchen sink with a discharge rate of 11.3 gallons per minute, and the same length of vertical waste pipe, a 1¼-in. bag trap could be installed without danger of self-siphonage occurring.

(5) The seal of none of the non-siphon traps tested, including the drum traps, could be broken by self-siphonage under conditions of maximum rate of flow through the trap.

In drawing these conclusions no consideration has been given to the drip which would fall into the trap after the discharge from the fixture is complete. This would be an added factor of safety against seal rupture.

10. *Transmission of Siphonage in Waste Pipes and Distance between a Trap and Its Vent.*—If it is found that the effect of a long waste pipe on the transmission of siphonage from a stack, or other waste pipe, to a trap is to reduce the intensity of the siphonage, it is possible that traps placed at the upper end of a long waste pipe may be provided with smaller vent pipes, or may even not require venting. It is concluded on page 45 of Bulletin No. 143 that:

". . . . the (back) pressure in all traps on the same waste pipe is the same" (regardless of distances up to 25 feet from the stack).

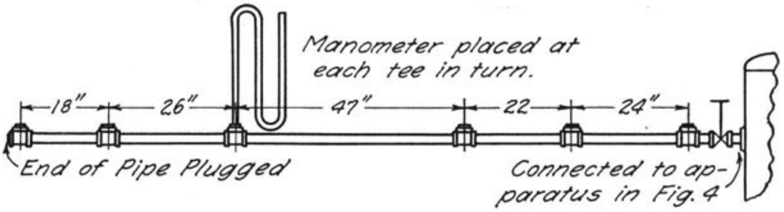


FIG. 11. APPARATUS FOR MEASURING SIPHONAGE AT VARIOUS DISTANCES FROM STACK

It would seem that the same condition should hold true for the transmission of siphonage as for back pressure. Tests were made, however, to determine the accuracy of such an assumption.

The apparatus used is shown in Fig. 11. When testing the intensity of vacuum in the waste pipe at different distances from the vacuum tank, no trap was used and the end of the waste pipe was closed. Measurements of intensity of vacuum at various distances from the vacuum tank were then made under similar conditions by means of the manometer shown in the figure. The results of these observations showed that the same intensity of vacuum existed at all points in the waste pipe.

When testing the effect of placing the vent at different distances from the trap the trap was placed on the end of the waste pipe furthest from the vacuum tank. The vent was moved successively to different positions and the vacuum or negative pressure required to siphon the trap was observed. The results are plotted in Fig. 12.

It is evident from the results shown in the figure that, where traps are unvented, the intensity of siphonage transmitted to a trap is practically independent of the ordinary lengths of waste pipes used in plumbing. Actually the intensity of the vacuum is slightly diminished by transmission through a waste pipe. Where the traps are well vented a greater intensity of siphonage is required to break the seal of a trap which is close to its vent than that of a trap which is far away from its vent. As the distance between the trap and the vent is increased, the intensity of siphonage necessary to break the seal of the trap is diminished.

It is impracticable from these tests to fix a limiting distance between a trap and its vent. The tests indicate merely that it is desirable to place a vent as near as possible to its trap and that a vent placed some distance away from a trap may become only one-half as effective as one close to the trap. It is obvious that a vent placed

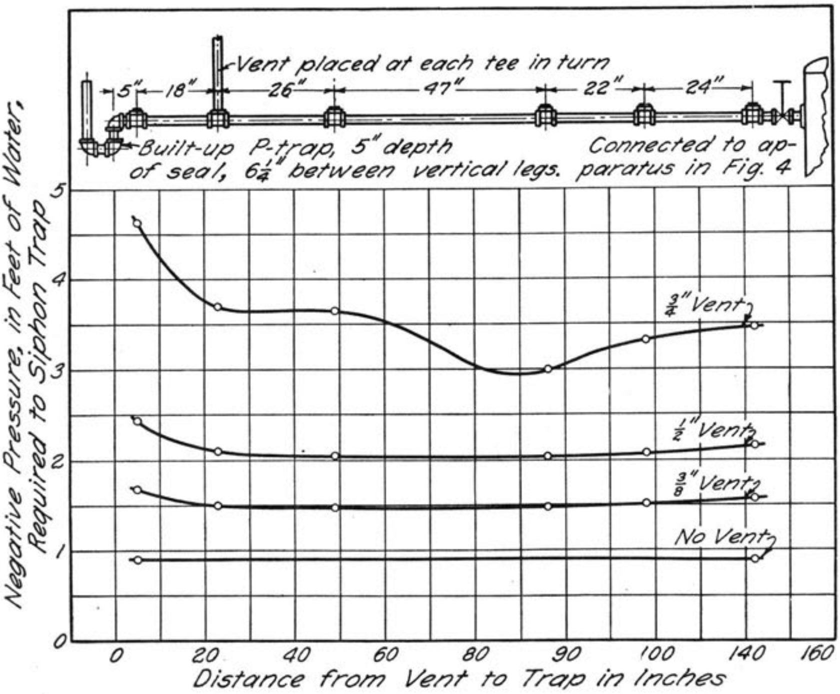


FIG. 12. EFFECT OF DISTANCE BETWEEN TRAP AND ITS VENT ON INTENSITY OF SIPHONAGE AT VARIOUS DISTANCES FROM STACK

a long distance away from a trap is valueless in preventing the self-siphonage of the trap.

11. *Connections at Lower End of Stacks.*—The connection at the base of a stack to the horizontal soil or waste pipe, usually the house drain, will be called the foot piece. It has been found that the type of this connection is an important factor in determining the pressures, both above and below atmospheric, which are created in plumbing systems. It is desirable, therefore, to determine the type of connection which will result in the lowest possible pressures within a plumbing system.

The apparatus used in making these tests consisted of a 4-in. vertical pipe, fifty feet long from the basement floor to the point at which water entered near the top. Piezometers for measuring the pressures in the vertical pipe were placed at various elevations, as shown in Fig. 13.

The foot piece to be tested was placed in position to connect the stack and the floor drain. Water was discharged into the top of the

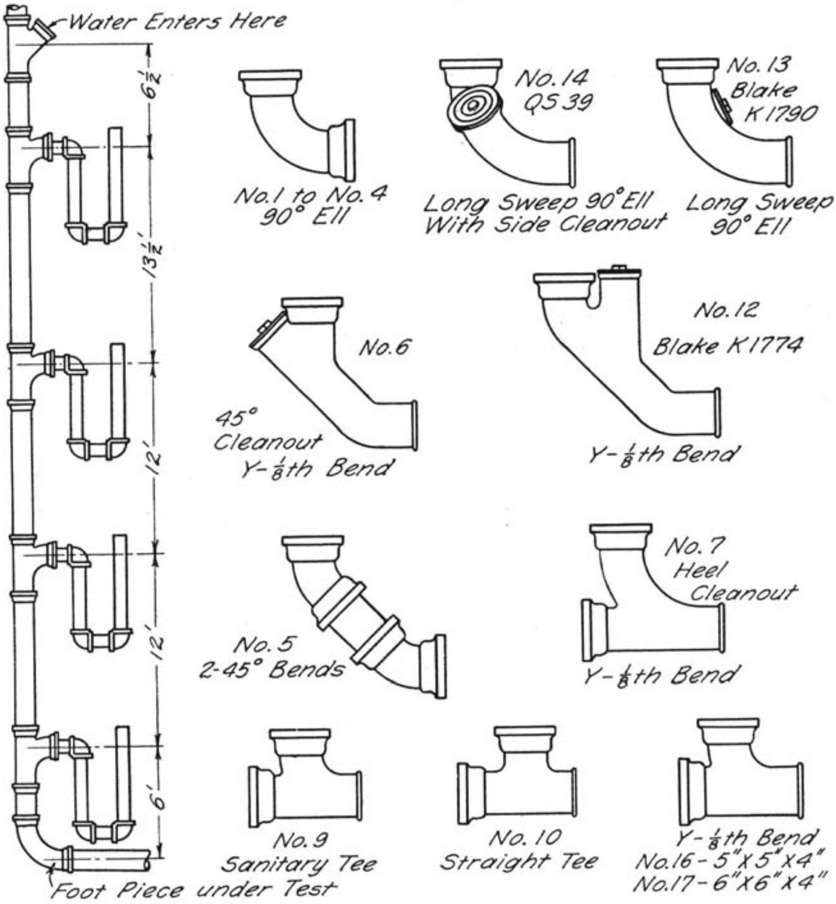


FIG. 13. APPARATUS FOR TESTING CONNECTION OR FOOT PIECE BETWEEN STACK AND HOUSE DRAIN AND TYPES OF BASE CONNECTIONS OR FOOT PIECES

stack at various rates for seven seconds and the pressures produced at different points in the stack were observed. The pressures produced at the same rates of discharge, with different foot pieces in place, were then compared for the purpose of drawing conclusions as to the most desirable type of foot piece.

The various types of foot pieces tested are illustrated in Fig. 13. The pressures produced are recorded in Table 5. In studying this table it should be noted that only pressures above atmospheric are produced at the basement and first floor, and only pressures below atmospheric are produced at the two upper floors. Actual observed

TABLE 5

COMPARISON OF TYPES OF BASE CONNECTIONS JOINING 4-IN. STACK TO EIGHT FEET OF 4-IN. HOUSE DRAIN

The types of fittings and apparatus used are shown in Fig. 13.

Description of Fitting	Fitting No. in Fig. 13	Relative Pressure in Terms of Pressure with Use of Long Sweep 90° Ell.			
		Basement	1st Floor	2nd Floor	3rd Floor
90° ell 12 in. radius	1	+1.0	+1.0	−1.0	−1.0
90° ell 5 in. radius	2	+1.77	+1.74	−0.86	−0.96
90° ell 4 in. radius	3	+2.80	+2.41	−0.95	−1.14
90° ell 3 in. radius	4	+3.61	+3.42	−0.92	−1.16
2-45° ells with 11 in. nipple	5	+2.10	+1.82	−0.80	−1.03
Y-⅛th bend, vertical cleanout	6	+2.44	+2.09	−1.44	−1.18
Y-⅛th bend, heel cleanout	7	+3.24	+2.91	−1.32	−1.40
Y-⅛th bend, heel cleanout, short pattern	8	+5.95	+5.45	−1.07	−1.39
No fitting at the base of the stack	(not shown)	−0.36	......	......	−1.52
Sanitary tee	9	+4.62	+4.32	−1.15	−1.40
Straight tee	10	+6.72	+7.09	−0.95	−1.16
Y-⅛th bend	12	+2.64	+2.06	−1.34	−1.42
Long-sweep ell	13	+1.19	+1.65	−1.50	−1.45
Long-sweep ell	14	+2.04	+1.53	−1.45	−1.47
Long-sweep ell	15	+1.45	+1.33	......	......
Y-⅛th bend 5″x5″x4″	16	+1.65	+1.08	−1.37	−1.41
Y-⅛th bend 6″x6″x4″	17	+1.62	+1.27	−1.40	−1.45

The figures in this table have been obtained by making from five to ten observations of pressure for each of fifteen different rates of discharge between 24 and 330 gal. per min. at each floor and for each base connection. The 15 averages of the observations at different rates of flow for one particular fitting at one floor were then added together and divided by 15. This quotient for each fitting was then divided by the quotient obtained at the corresponding floor for a 90°-ell with 12-in. radius. The sums of the 15 averages obtained with the 90°-ell with 12-in. radius were: basement, 4.01; 1st floor, 2.89; 2nd floor, 9.93; and 3rd floor, 9.96.

The pressures at the 2nd and 3rd floors were always less than atmospheric, and at the basement and 1st floors were always greater than atmospheric, except for the one case noted with a negative sign at the basement.

pressures are not recorded in the table as they are dependent upon factors fixed by the piping connections. Only the relative intensities of pressure are significant. It should be noted also that the type of foot piece has no marked effect upon the intensity of the pressures at the upper floors. This is to be expected, as the intensity of siphonage is determined by the quantity of water falling and its rate of acceleration in the upper regions of the stack. Neither of these factors will be materially affected by the type of foot piece.

It is concluded, from a study of the results presented in Table 5, that a long-sweep 90-deg. ell is the best type of foot piece to be used on any stack, and that a right-angled, tee-shaped fitting is the poorest type. An arrangement of two 45-deg. ells with a nipple between them, which is frequently used in practice, is not so satisfactory as a medium-sweep or a long-sweep 90-deg. ell, but it is better than a short-sweep 90-deg. ell. The use of over-size fittings as foot pieces, such as a 6 in. x 6 in. x 4 in. sanitary tee is shown to be less advantageous than a long sweep 90-deg. ell of the same size as the stack and house drain.

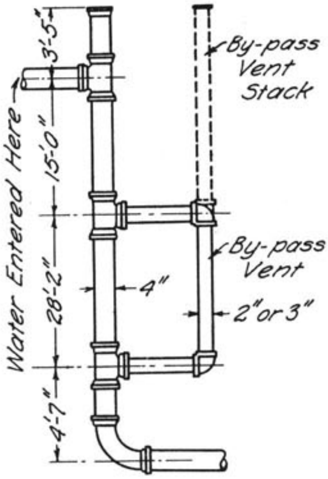


FIG. 14. APPARATUS FOR STUDY OF BY-PASS VENTING

12. *By-pass Venting.*—A vent pipe connected at two or more points to a soil or waste stack is called a by-pass vent. When the upper end of the vent pipe is open to the atmosphere it is called a by-pass vent stack. A by-pass vent, a by-pass vent stack, and the arrangement of piping used in testing the effectiveness of by-pass vents are illustrated in Fig. 14.

The effectiveness of by-pass vents was expected to be great because of the probability that the vent would conduct pressures higher than atmospheric into regions of pressure lower than atmospheric, each pressure tending to neutralize the other. The results of the tests fulfilled the expectations to a marked degree and emphasized the effectiveness of by-pass venting.

The first arrangement of by-pass venting subjected to test consisted of a 2-in. vent pipe connected to a low heel outlet at the base of a 4-in. soil stack which was 50 ft. high. The upper end of the 2-in. vent pipe was left open in one test, and in another it was connected to the 4-in. stack about 5 feet above the base of the stack. Water was discharged down the stack at various rates. The pressures at different elevations in the stack were observed through piezometers as illustrated in Fig. 13. No difference was observed between the pressures produced without a vent and those produced when the by-pass vent was connected in either manner as described. Further tests demonstrated that the connection of the vent to the lowest point of the fitting at the base was faulty because water, accumulating

TABLE 6
EFFECT OF BY-PASS VENTING

Condition of Venting	Relative Pressures, in Terms of Pressure for Unvented Stack			
	Basement	1st Floor	2nd Floor	3rd Floor
4-in. Stack without vent	1.00	1.00	1.00	1.00
4-in. Stack with 2-in. By-pass Vent	0.72	0.59	0.74	0.60
4-in. Stack with 3-in. By-pass Vent	0.58	0.42	0.73	0.50
4-in. Stack with 3-in. By-pass Vent Stack.	0.74	0.33	0.43	0.18
4-in. Stack with 3-in. Manifold By-pass Vent	0.72	0.34	0.55	0.33
4-in. Stack with 3-in. Manifold By-pass Vent Stack	0.78	0.26	0.05	0.17

The figures in this table were obtained by a similar computation to that used in obtaining those shown in Table 5.

at the base of the stack, submerged the vent pipe opening and prevented the movement of air in it.

The connections used in the tests which demonstrated the effectiveness of by-pass venting are illustrated in Fig. 14. It is to be noted that the lower end of the vent pipe is connected to the stack 4 ft. 7 in. above the base, a height to which water will not ordinarily back up. The upper end of the vent pipe is carried up into the region of siphonage in the soil stack. Tests were made with 2-in. and 3-in. by-pass vents and by-pass vent stacks, and with manifold by-pass vents. A manifold by-pass vent is a by-pass vent connected to the stack at more than two points. The pressures observed when water was discharged down the soil stack, with and without the vent connections, are shown in Table 6.

The effectiveness of by-pass venting is evident from this table. The 3-in. manifold by-pass vent stack is seen to be the most effective in reducing the pressures below the values observed when no vent was used. The pressure reductions due to the use of the vent in this case were as follows: at the basement, 22 per cent; at the first floor, 74 per cent; at the second floor, 95 per cent; and at the third floor, 83 per cent.

It is concluded from a study of by-pass venting and foot pieces at the base of stacks that the capacity of plumbing systems can be greatly increased, or that the size and number of vent pipes required in a large building may be greatly diminished, as compared with the requirements of ordinary practice today. If the requirements of present-day practice concerning sizes of stacks, vents, etc., are adhered to a greater factor of safety against seal rupture can be obtained by the use of the proper type of foot piece and the installation of by-pass vents on stacks.

TABLE 7
RATES OF DISCHARGE FROM FAUCETS

Type of Faucet	No.	Discharge in Gallons per Minute for Pressure of			
		6 in. of water	5 lb. per sq. in.	30 lb. per sq. in.	90 lb. per sq. in.
¾-in. Compression Sink Faucet,					
Wide Open	1	1.8	8.1	20.0	33.4
¾ Open	1	1.8	...	19.5	32.8
½ Open	1	1.8	7.6	19.0	32.9
¼ Open	1	1.5	7.0	17.4	29.9
½-in. Compression Sink Faucet, Wide Open	2	1.4	6.0	14.8	24.5
½-in. Compression Sink Faucet, Wide Open	3	1.2	5.6	13.6	23.4
½-in. Compression Sink Faucet, Wide Open	4	1.4	6.1	15.5	27.0
½-in. Ground Key Sink Faucet, Wide Open	5	2.2	9.5	23.4	36.4
¾-in. Ground Key Sink Faucet, Wide Open	6	3.0	13.8	31.7	51.0
¾-in. Compression Sink Faucet, Wide Open	7	2.0	9.0	22.1	36.0
½-in. Self-closing Compression Faucet, Wide Open.	8	0.6	2.6	6.8	11.7
⅜-in. Ground Key Sink Faucet, Wide Open	9	1.5	6.8	16.7	27.7
⅜-in. Compression Sink Faucet, Wide Open	10	0.8	3.2	8.2	14.1
½-in. Compression Sink Faucet, Wide Open	11	1.1	4.8	12.3	21.3
½-in. Compression Laundry Tray Faucet, Open	12	1.4	6.3	17.3	25.3
Compression Wash Basin Faucet, Wide Open	13	1.7	5.0	11.9	21.3
Compression Wash Basin Faucet, Wide Open	14	1.9	6.4	15.6	27.6
1-in. Ground Key Sink Faucet, Wide Open	15	7.2	30.7	78.9	118.8
1-in. Compression Sink Faucet, Wide Open	16	3.5	12.7	39.9	64.8
Combination Laundry Faucet, Compression,					
Both Outlets Wide Open	17	2.3	9.6	22.4	38.6
Either Hot or Cold, Wide Open	17	1.4	6.1	14.4	24.8
Combination Compression Bath Tub Faucet,					
Both Sides Open, Without Nozzle	18	...	8.0	20.4	34.4
Both Sides Open, With Nozzle		1.5	5.9	14.3	24.8
Hot Open, Cold Closed, No Nozzle		...	4.3	11.1	19.9
Hot Open, Cold Closed, With Nozzle		...	4.1	10.0	17.9
Cold Open, Hot Closed, With Nozzle		0.9	3.8	9.2	16.1
Cold Open, Hot Closed, No Nozzle		...	...	10.5	17.0
Combination Compression Bath Tub Faucet,					
Hot and Cold Open, With Nozzle	19	0.94	4.8	11.9	19.4
Hot or Cold Open, With Nozzle		0.96	3.8	9.3	15.9
Combination Compression Bath Tub Faucet,					
Hot and Cold Open, Without Nozzle	20	1.55	6.6	15.8	27.7
Hot and Cold Open, With Nozzle		1.13	4.5	11.4	19.6
Hot or Cold Open, Without Nozzle		0.86	3.6	7.8	15.1
Hot or Cold Open, With Nozzle		0.82	3.1	7.6	13.3
Combination Compression Sink Faucet With Swinging Nozzle, Straight Connection,					
Hot and Cold Open	21	0.97	4.6	12.2	21.4
Hot Open, Cold Closed		0.72	3.3	8.6	15.1
Cold Open, Hot Closed		0.69	3.1	8.2	14.5
Ditto, 90° Bends and Vertical Connection,					
Hot and Cold Open	21	1.21	4.9	12.3	21.2
Hot or Cold Open		0.78	3.4	8.3	14.4
Combination Compression High Goose Neck Pantry Sink,					
Hot and Cold Open	22	0.88	4.6	11.6	20.9
Hot Open, Cold Closed		0.63	3.3	8.3	14.7
Cold Open, Hot Closed		0.49	2.6	6.7	11.9

III. LOSS OF PRESSURE IN FAUCETS

13. *Loss of Pressure in Faucets.*—In the design of the water supply pipes for a building some of the factors entering into the determination of the sizes of the pipes are the rate at which the water is to be delivered, the pressure desired at the point of delivery, and the fric-

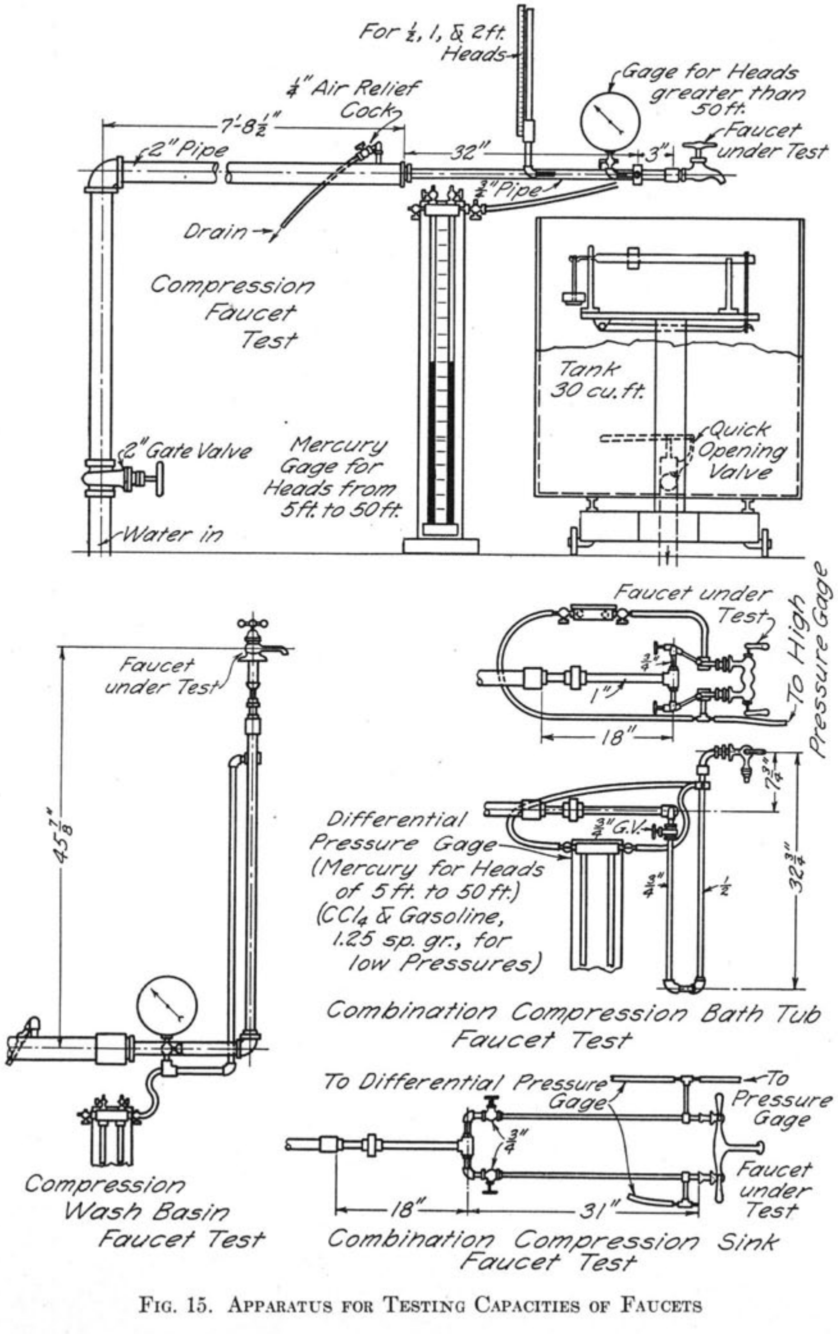
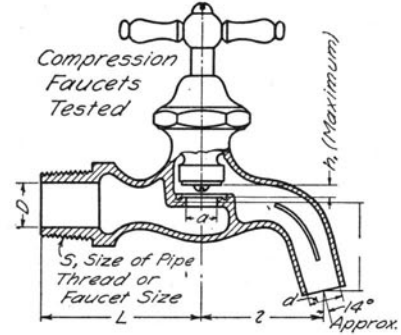
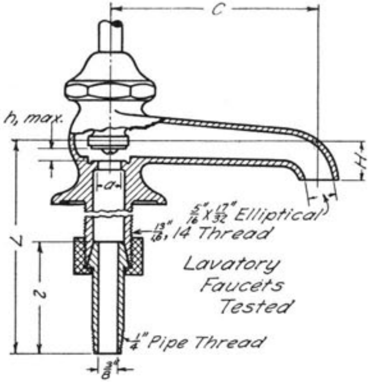


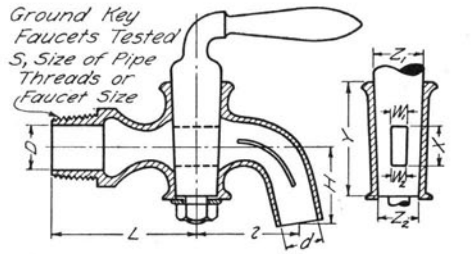
FIG. 15. APPARATUS FOR TESTING CAPACITIES OF FAUCETS



Faucet Number	Dimensions in Inches							
	S	D	d	L	l	H	h	a
1	$\frac{3}{4}$		$\frac{5}{8}$	$2\frac{5}{8}$	2	$1\frac{1}{2}$	0.38	$\frac{1}{2}$
2	$\frac{1}{2}$		$\frac{15}{32}$	$2\frac{1}{4}$	$1\frac{13}{16}$	$1\frac{5}{16}$	0.30	$\frac{15}{32}$
3	$\frac{1}{2}$		$\frac{15}{32}$	$3\frac{9}{16}$	$1\frac{13}{16}$	$1\frac{5}{16}$	0.13	$\frac{15}{32}$
4	$\frac{1}{2}$		$\frac{15}{32}$	$2\frac{1}{4}$	$1\frac{13}{16}$	$1\frac{5}{16}$	0.15	$\frac{15}{32}$
7	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$2\frac{9}{16}$	$1\frac{15}{16}$	$1\frac{3}{8}$	0.27	$\frac{9}{16}$
10	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{15}{16}$	$1\frac{7}{16}$	$\frac{7}{8}$	0.25	$\frac{3}{8}$
11	$\frac{1}{2}$	$\frac{15}{32}$	$\frac{1}{2}$	$2\frac{7}{16}$	$1\frac{3}{4}$	$1\frac{1}{8}$	0.23	$\frac{3}{8}$
16	1	1	$\frac{15}{16}$	$3\frac{5}{16}$	$2\frac{9}{16}$	$1\frac{5}{8}$	0.30	$\frac{13}{16}$
8	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$2\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{3}{16}$	0.80	$\frac{11}{32}$



Faucet Number	Dimensions in Inches					
	L	l	C	H	h	a
13	$4\frac{15}{16}$	$1\frac{13}{16}$	$3\frac{1}{2}$	$\frac{3}{4}$	0.17	$\frac{3}{8}$
14	$4\frac{13}{16}$	$1\frac{5}{8}$	$3\frac{3}{8}$	$\frac{1}{2}$	0.33	$\frac{15}{32}$



Faucet Number	Dimensions in Inches											
	S	D	d	L	l	H	W_1	W_2	X	Y	Z_1	Z_2
5	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$2\frac{3}{16}$	$1\frac{7}{16}$	$1\frac{1}{8}$	$\frac{1}{4}$	$\frac{7}{32}$	$\frac{9}{16}$	$1\frac{5}{8}$	$\frac{11}{16}$	$\frac{9}{16}$
6	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{19}{32}$	$2\frac{3}{8}$	$1\frac{11}{16}$	$1\frac{1}{4}$	$\frac{9}{32}$	$\frac{1}{4}$	$\frac{21}{32}$	$1\frac{7}{8}$	$\frac{13}{16}$	$\frac{11}{16}$
9	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{25}{64}$	$1\frac{7}{8}$	$1\frac{5}{16}$	1	$\frac{7}{32}$	$\frac{3}{16}$	$\frac{9}{16}$	$1\frac{9}{16}$	$\frac{5}{8}$	$\frac{1}{2}$
15	1	1	$\frac{29}{32}$	3	$2\frac{5}{16}$	$1\frac{3}{4}$	$\frac{7}{16}$	$\frac{3}{8}$	$1\frac{1}{16}$	$2\frac{3}{8}$	$1\frac{1}{16}$	$\frac{7}{8}$

$\frac{1}{2}$" Laundry Tray Faucet

Faucet Number 12

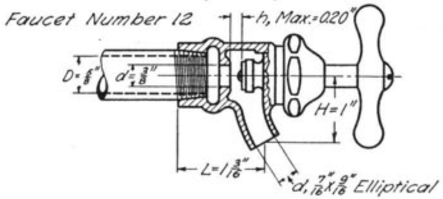


FIG. 16. TYPES OF FAUCETS TESTED

tion losses in the pipes, fittings, valves, and faucets. Results on tests of friction losses in pipes, fittings, and valves have been reported in various publications.*

Tests of the pressure losses in faucets are reported herein as an addition to such information. It is assumed that the results of these tests on faucets may also be of use in pointing out defects in existing faucet design, and in assisting in the selection of faucets for particular services.

Many styles of ground key and compression faucets were tested, as is indicated in Table 7. The apparatus used in making the tests is shown in Fig. 15 and the details of some of the faucets tested are shown in Fig. 16. For the various faucets tested changes in the piping connections were necessary in order that the faucets might be set up in the manner for which they were designed. In every case a piece of straight pipe not less than 50 diameters in length was used above the faucet connection in order to minimize possible effects of turbulent flow through the faucet. The pressure at the faucet was read by means of a gage placed as close as possible to the faucet, as shown in Fig. 15. The type of gage used was suited to the intensity of pressure occurring in any particular test. The pressure observed on the gage which was connected to the supply pipe was recorded as the loss of pressure through the faucet. The rate of flow through the faucet was measured by catching the water discharged in a tank which rested on weighing scales. The time taken to discharge a given quantity of water was observed by means of a stop watch.

In studying the results given in Table 7, the pressure losses through certain faucets are seen to be very large, particularly in compression faucets. The capacities of ground key faucets are seen to be double the capacities of compression faucets of the same size, for the same pressure. An examination of the construction of compression faucets will show the reason for this. The passages are tortuous and roughly finished, and much head is lost through the sharp turn as water issues between the valve disc and its seat. It is probable that the loss of pressure in compression faucets could be appreciably reduced by redesigning the passages through the faucet. Little,

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*"The Friction of Water in Pipes and Fittings," Univ. of Texas Bul. 1759, Oct. 20, 1917.

"Experiments on Loss of Head in Valves and Pipes of One-half to Twelve Inches Diameter," Bul. of the Univ. of Wis., Eng. Series, Vol. IX, No. 1, Nov., 1922.

"Flow of Water Through One and One-half Inch Pipe and Valves," Purdue Univ. Eng. Exp. Sta. Bul. 1, July, 1918.

Perry, Lynn, "Tests of Loss of Head in Standard Elbows and Tees," Engineering News-Record, Vol. 92, p. 940, May 29, 1924.

"Hydraulic Experiments with Valves, Orifices, Hose, Nozzles, and Orifice Buckets," Univ. of Ill. Eng. Exp. Sta. Bul. 105, 1918.

Timmis, W. S., "Water Pipe Sizes for Plumbing Fixtures, Branches, and Mains," Jour. A. S. H. and V. E., Vol. 28, p. 397, 1922.

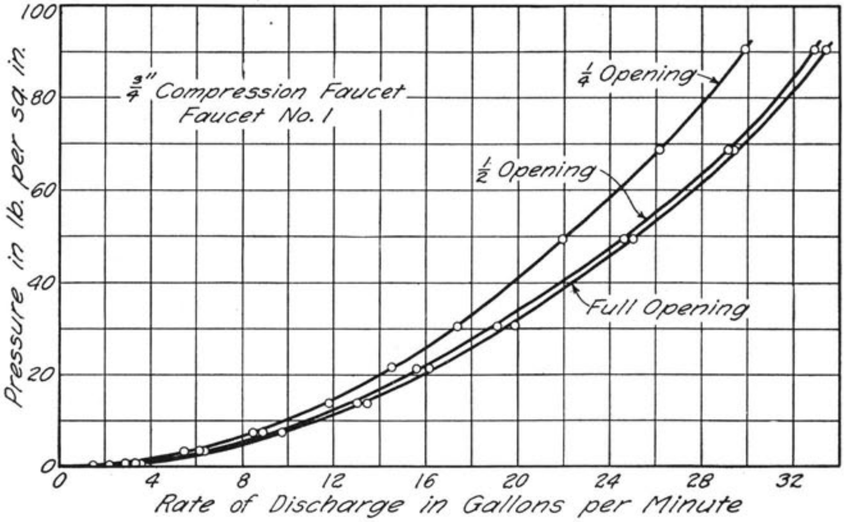

FIG. 17. DISCHARGE CURVES FOR ¾-IN. COMPRESSION FAUCET

if any, advantage would be secured by increasing the lift of the disc. This fact is indicated by the results shown in Fig. 17. This figure shows for any given rate of discharge, a decrease of head loss between the one-fourth open and the one-half open positions of about twenty-five per cent, but as the faucet is opened further, that is as the lift of the disc is increased, the further decrease in head loss is only about three per cent.

IV. TESTS ON MIXING VALVES OF SHOWER BATHS

14. *Piping for Batteries of Shower Baths.*—Where batteries of shower baths are used, as in gymnasiums, bath houses, etc., with hand-adjusted or inadequate mixing valves to control the temperature of the water at the shower, difficulty is often encountered by the bather in maintaining a comfortable temperature for the bath and occasionally serious scalding may result when hot water issues unexpectedly from the shower head. When one shower bath is the only outlet on a plumbing system and the temperature of the water is controlled by manually operated valves under the hands of the bather the danger from scalding is so remote as to be negligible. Such an equipment is rare, however. When there are other outlets on the plumbing system, particularly other shower baths near to the one in operation, the danger of possible scalding increases with the number

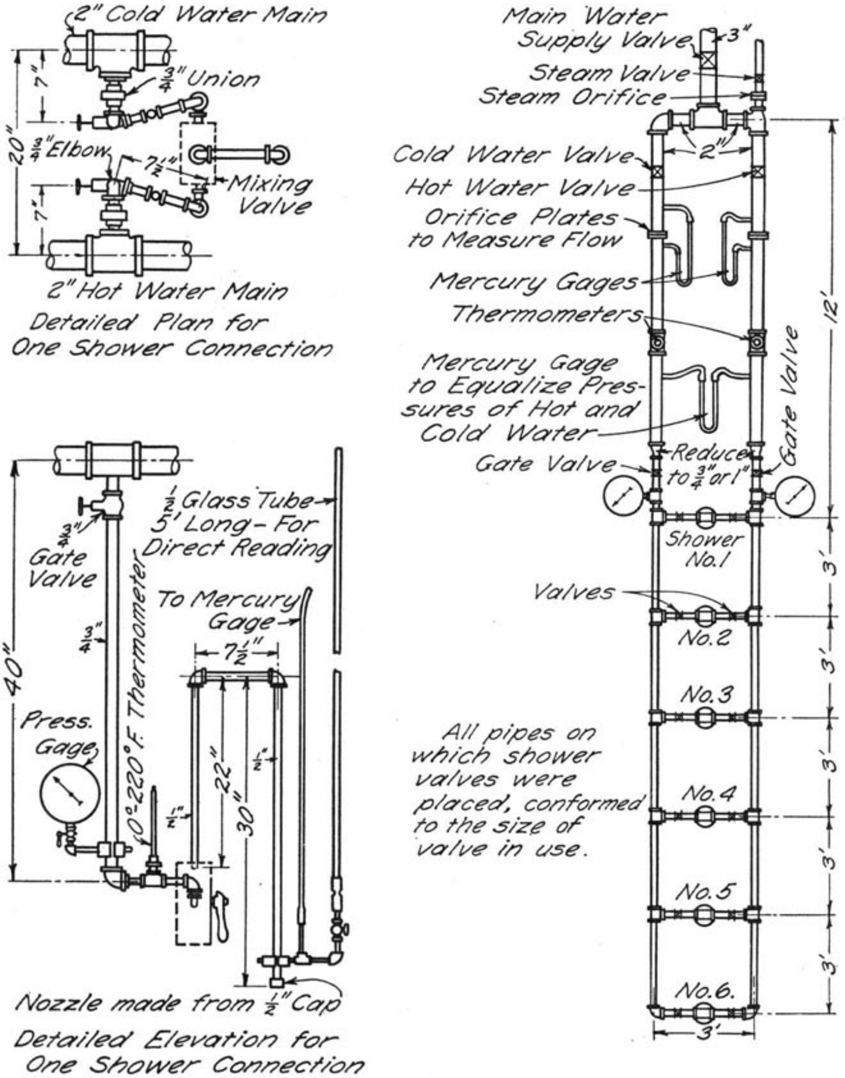

FIG. 18. APPARATUS USED FOR TESTING SHOWER BATH PIPING

of outlets which may be turned on or off while any one shower bath is in use. The pressures and temperatures of the hot and cold water are also important factors in affecting the probability of scalding.

The temperature at which water will issue from any shower can be computed if certain assumptions are made as to the piping arrangements, friction losses, temperature of hot and cold water supplies, arrangement of valves, etc. A common arrangement of piping for a battery of showers is shown in Fig. 18. With this arrangement of piping if it is assumed

(1) that the pressures in the hot-water and cold-water supplies remain equal,

(2) that the losses of head in the main hot-water and cold-water supply pipes are negligible due to their large size,

(3) that the loss of head in all showers is the same for the same rate of discharge,

(4) that the rate of flow from all shower heads is the same provided either the hot-water or the cold-water supply valves, or both supply valves, to the shower are open,

then the computed temperatures of water issuing from each shower, with different arrangements of valves, will be as given in Tables 8 to 11, inclusive.

The computations of temperature have been made from the expression

$$T_m = \frac{Q_c \times T_c + Q_h \times T_h}{Q_c + Q_h}$$

in which Q_c is the rate of flow of cold water to the shower, Q_h is the rate of flow of hot water to the shower, T_m is the temperature of the mixture, T_h is the temperature of the hot water, and T_c is the temperature of the cold water.

The accuracy of these assumptions and computations was studied by a series of tests to determine (1) the changes of rate of discharge and temperature at shower heads caused by pressure variations in hot-water and cold-water supply lines, the regulating valves to each shower remaining in a fixed position, and (2) the changes in rate of discharge and temperature at shower heads caused by moving one or more shower regulating valves in the same battery of showers, (a) when the temperature and rate of supply of hot water and cold water to the battery of showers remains constant, and (b) when the temperature and rate of supply of hot water and cold water to the battery of showers is allowed to vary.

The changes in temperature at any shower will occur with the same rapidity with which a valve on the same or any other shower can be operated. It is evident that with the arrangement of piping shown in Fig. 18 it is possible for one or more bathers to be scalded or chilled.

The apparatus used for making these tests is illustrated in Fig. 18. Hot water was obtained by injecting steam into the cold water

TABLE 8

COMPUTED TEMPERATURES AT SHOWER HEADS WITH PIPING ARRANGEMENTS AS SHOWN IN FIGURE 18

The temperature of the hot water supply is 180 deg. F.
The temperature of the cold water supply is 60 deg. F.
The rate of supply of both hot and cold water to the showers is equal, each representing one-half the total flow.
The discharge from each shower is always 6 gal. per min.
All valves to showers 4, 5, and 6 are closed.

Valve Arrangement Number	Position of Valves			Rate of Supply of Hot Water to Each Shower gal. per min.			Rate of Supply of Cold Water to Each Shower gal. per min.			Temperature at Each Shower, deg. F.		
	Shower No. 1	Shower No. 2	Shower No. 3	Shower No. 1	Shower No. 2	Shower No. 3	Shower No. 1	Shower No. 2	Shower No. 3	Shower No. 1	Shower No. 2	Shower No. 3
1	All Open	All Open	All Open	3	3	3	3	3	3	120	120	120
2	H closed C closed	H open C open	H open C open	0	3	3	0	3	3	...	120	120
3	H closed C closed	H closed C closed	H open C open	0	0	3	0	0	3	...	...	120
4	H open C open	H closed C open	H open C open	4.5	0	4.5	1.5	6	1.5	150	60	150
5	H closed C open	H closed C open	H open C open	0	3	6	6	3	0	60	120	180
6	H closed C open	H open C open	H closed C open	0	6	3	6	0	3	60	180	120
7	H closed C open	H open C open	H open C open	0	4.5	4.5	6	1.5	1.5	60	150	150

TABLE 9

TEMPERATURES, PRESSURES, AND RATES OF DISCHARGE IN BATTERY OF THREE SHOWER HEADS

With piping arrangement as shown in Fig. 18. Unequal quantities of hot and cold water, all valves to showers 4, 5, and 6 closed.

Test No.	Shower Heads Numbered Have Their Hot-Water Valves Closed*	Rate of Flow to all Three Showers gal. per min.		Temperatures Deg. F.		Shower Discharges											
						Temperature at Each Shower Head., deg. F.						Pressure at Each Shower Head. ft. of water			Rate of Flow from Each Shower Hd. gal. per min.		
						Shower Number						Shower Number			Shower Number		
						1		2		3		1	2	3	1	2	3
		Hot Water	Cold Water	Hot Water	Cold Water	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.						
1	ll Open	9.4	3.7	138	70	124	119	124	119	122	119	4.0	4.0	3.8	4.4	4.4	4.3
2	1	9.0	3.4	142	70	84	79	142	142	141	142	3.1	3.8	3.6	3.9	4.3	4.2
3	2	8.5	3.3	146	70	146	146	83	77	145	146	3.5	3.2	3.4	4.1	3.9	4.1
4	3	8.5	3.3	146	70	147	146	146	146	85	78	3.6	3.2	2.9	4.2	3.9	3.8
5	1, 2	8.6	3.3	145	70	115	83	115	145	145	145	3.1	3.1	3.4	3.9	3.9	4.0
6	2, 3	9.0	3.8	144	70	145	144	145	109	86	109	4.8	3.7	3.4	4.8	4.2	4.0
7	1, 3	8.9	3.5	144	70	145	76	145	144	87	144	3.4	4.1	3.1	4.1	4.4	3.9
8	All Open	5.1	8.2	196	71	120	119	122	119	122	119	4.0	3.9	3.7	4.4	4.4	4.2
9	1	5.0	8.2	197	71	71	71	148	143	144	143	3.5	4.0	3.9	4.1	4.4	4.4
10	2	4.9	8.0	202	71	149	145	72	72	145	145	3.8	3.4	3.4	4.3	4.1	4.1
11	3	4.8	7.9	206	72	150	149	152	149	72	72	3.7	3.6	2.9	4.3	4.2	3.8
12	1, 2	4.9	8.1	214	74	95	74	94	104	208	214	4.1	4.0	3.1	4.5	4.4	3.9
13	1, 3	5.1	8.2	208	74	112	74	206	208	74	93	4.2	4.1	3.7	4.5	4.5	4.3
14	2, 3	5.2	8.2	202	74	201	202	110	83	74	83	4.4	4.15	3.6	4.6	4.5	4.2

*All cold-water valves are open.

TABLE 10

TEMPERATURES, PRESSURES, AND RATES OF DISCHARGE IN BATTERY OF SIX SHOWER HEADS

Equal Quantities of Hot and Cold Water.

Test No.	Shower Heads Numbered Have Their Hot-Water Valves Closed. All Cold-Water Valves Open	Rate of Flow to all Six Showers, gal. per min.		Temperatures deg. F.		Temperatures at Each Shower Head, deg. F.											
						1		2		3		4		5		6	
		Hot Water	Cold Water	Hot Water	Cold Water	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.
1	All Open	12.7	12.7	152	68	108	110	112	110	110	110	112	110	112	110	110	110
2	6	13.9	13.4	140	72	118	114	113	114	109	114	116	114	116	114	72	72
3	5, 6	12.7	12.7	145	72	135	123	126	123	118	123	130	123	72	72	72	72
4	4, 5, 6	13.4	13.0	141	72	141	141	142	141	142	141	87	72	72	72	72	72
5	3, 4, 5, 6	12.7	13.5	144	71	146	144	145	144	143	86	76	86	72	86	71	86
6	2, 3, 4, 5, 6	12.9	13.2	136	71	136	136	136	96	136	96	82	96	71	96	71	96
7	1, 2, 3	13.6	12.9	174	71	72	71	72	71	72	71	171	174	164	174	153	174
8	1, 2, 3, 4	13.4	12.9	174	71.5	93	72	92	72	92	72	90	174	173	174	174	174
9	1, 2, 3, 4, 5	12.9	12.7	170	71	108	71	108	71	108	71	108	170	109	170	171	170
10	1	13.2	13.1	172	71.5	72	72	131	132	132	132	132	132	130	132	122	132
11	2, 3, 4, 5	12.7	12.9	184	71	181	184	141	71	82	71	80	71	81	184	184	184
12	3, 4	13.1	12.9	180	71	149	154	148	154	72	71	71	71	148	154	138	154

SHOWER DISCHARGES

Test No.	Pressure at Each Shower Head, ft. of water						Rate of Flow from Each Shower Head, gal. per min.					
	1	2	3	4	5	6	1	2	3	4	5	6
1	3.65	3.75	3.65	3.6	3.65	3.3	4.2	4.3	4.2	4.2	4.2	4.0
2	4.15	4.25	4.15	4.25	4.35	3.9	4.5	4.5	4.5	4.5	4.6	4.4
3	3.9	3.95	3.85	3.95	3.85	3.6	4.4	4.4	4.3	4.4	4.3	4.2
4	4.2	4.4	4.2	4.15	4.1	3.95	4.5	4.6	4.5	4.5	4.1	4.4
5	4.25	4.35	4.0	4.0	4.05	3.8	4.5	4.6	4.4	4.4	4.4	4.3
6	4.35	4.35	4.15	3.95	4.15	3.95	4.6	4.6	4.5	4.4	4.5	4.4
7	4.1	4.1	4.0	4.25	4.2	4.0	4.5	4.5	4.4	4.5	4.5	4.0
8	4.15	4.25	4.05	4.15	4.15	4.05	4.5	4.5	4.4	4.5	4.5	4.4
9	3.9	4.0	3.85	3.85	3.95	3.85	4.4	4.4	4.3	4.3	4.4	4.3
10	4.1	4.3	4.15	4.25	4.25	3.95	4.5	4.6	4.5	4.5	4.5	4.4
11	4.2	4.25	4.0	4.0	4.2	4.0	4.5	4.5	4.4	4.0	4.5	4.4
12	4.3	4.4	3.9	3.9	4.3	4.0	4.6	4.6	4.4	4.4	4.6	4.4

TABLE 11

TEMPERATURES, PRESSURES, AND RATES OF DISCHARGE IN BATTERY OF SIX SHOWER HEADS

Unequal Quantities of Hot and Cold Water.

Test No.	Shower Heads Numbered Have Their Hot-Water Valves Closed. All Cold-Water Valves Open	Rate of Flow to all Six Showers gal. per min.		Temperatures, deg. F.		Temperature at Each Shower Head, deg. F.											
						1		2		3		4		5		6	
		Hot Water	Cold Water	Hot Water	Cold Water	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.	Obs.	Comp.
1	All Open	20.2	8.3	144	69	124	121	124	121	128	121	123	121	121	121	116	121
2	6	19.3	7.3	143	69	143	134	143	134	129	134	138	134	130	134	69	69
3	5, 6	20.4	7.8	137	68	138	137	138	137	138	137	138	137	107	80	69	80
4	4, 5, 6	20.0	7.5	143	69	142	143	142	143	142	143	142	103	131	103	69	103
5	3, 4, 5, 6	20.1	7.2	141	69	142	142	142	142	142	112	142	112	119	112	69	112
6	2, 3, 4, 5, 6	19.7	6.8	146	69	145	146	145	122	146	122	146	122	121	122	69	122
7	1	20.2	8.2	144	70	70	70	139	130	140	130	132	130	129	130	122	130
8	1, 2	19.5	7.9	141	70	82	70	80	94	140	141	141	141	141	141	130	141
9	1, 2, 3	19.6	7.7	142	70	96	70	96	94	94	142	142	142	142	142	142	142
10	2, 3, 4, 5	19.6	8.0	140	70	140	140	140	70	110	91	96	140	96	140	140	140

SHOWER DISCHARGES

Test No.	Pressure at Each Shower Head, ft. of Water						Rate of Flow from Each Shower Head, gal. per min.					
	1	2	3	4	5	6	1	2	3	4	5	6
1	4.6	4.6	4.55	4.6	4.6	4.4	4.7	4.7	4.7	4.7	4.7	4.6
2	4.15	4.2	4.2	4.15	4.05	3.95	4.5	4.5	4.5	4.5	4.4	4.4
3	4.6	4.6	4.55	4.5	4.25	4.2	4.7	4.7	4.7	4.7	4.5	4.5
4	4.3	4.4	4.1	4.15	4.1	3.95	4.6	4.6	4.5	4.5	4.5	4.4
5	4.45	4.6	4.25	4.25	4.25	4.0	4.6	4.7	4.5	4.5	4.5	4.4
6	4.3	3.95	3.9	3.9	3.85	3.7	4.6	4.4	4.4	4.3	4.3	4.2
7	4.35	4.65	4.45	4.65	4.6	4.35	4.6	4.7	4.6	4.7	4.7	4.6
8	4.15	4.15	3.85	4.25	4.3	4.05	4.5	4.5	4.3	4.5	4.6	4.4
9	4.1	4.15	3.75	4.25	4.35	3.95	4.5	4.5	4.3	4.5	4.6	4.4
10	4.35	4.3	4.1	4.2	4.2	4.15	4.6	4.6	4.5	4.5	4.5	4.5

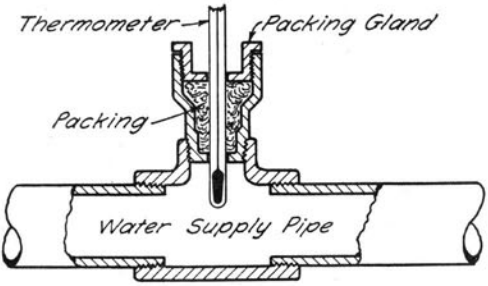

FIG. 19. METHOD OF INSERTING THERMOMETERS INTO PIPES

through the steam valve and orifice indicated in the drawing. The control of the flow of steam and water was such that the temperature of the hot-water supply could be easily and quickly adjusted and maintained within 2 deg. F. of any desired temperature. The rates of flow of the hot and the cold water were measured by means of the drop in pressure across calibrated orifices placed in each supply line. The temperatures of the main hot-water and cold-water supplies were observed by means of thermometers placed in the line. These thermometers were inserted into the pipes by a connection illustrated in Fig. 19. Valves beyond these thermometers were used in controlling the pressures and rates of flow of the hot and the cold water. The pressures in the hot-water and cold-water pipes were observed by means of pressure gages, and were maintained equal in all tests by the manipulation of valves. Standard shower heads were not used because of difficulties encountered in the preliminary tests in obtaining six shower heads which would give exactly the same rate of discharge under the same pressure. Difficulty also arose through the clogging of the shower sprays during a test because of jute in the laboratory water supply, this changing the rate of discharge. Calibrated orifices were used, therefore, in place of shower heads. The rates of discharge through all orifices were maintained the same, in any one test, by the manipulation of a valve connected to the shower discharge pipe just above the orifice used in place of the shower head. The pressure at this point was indicated by means of a water or a mercury gage, as shown in Fig. 18. The temperature of the water issuing from the orifice was measured by inserting a thermometer in the stream.

The temperatures observed with different combinations of valves open and closed are shown in Tables 9, 10, and 11. It is evident from a study of these tables that the loss of head in the main supply lines has some effect on the temperatures at the showers. This is shown in line 7 of Table 10. Here, the temperatures at showers 4, 5, and 6, respectively, are progressively reduced because a greater proportion of hot water goes to shower 4 than to shower 6, due to the loss of head in the hot water supply line. This condition is also illustrated in lines 1 and 2 of Table 11. Some marked differences are to be noted between the observed and the computed pressures. For example, in the case corresponding to line 5 of Table 10, hot water flows through valve 2 into the cold water pipe. It would be expected that this water would mix with the cold water in the cold-water supply pipe. On the contrary, it flows directly into the cold water valve of shower No. 3, delivering water thereto through the cold water valve *at a scalding temperature*. It is evident that both cold water and hot water are flowing in the same pipe at the same time without mixing, because water at a lower temperature than that in shower No. 3 flows on to be discharged through showers 4, 5, and 6. In lines 8 and 9 of Table 10 and line 12 of Table 9 an unexpected mixing of hot water and cold water is observed. Here hot water enters the cold-water pipe through the further valve and, flowing contrary to the normal direction of flow, enters both cold-water valves Nos. 1 and 2 (line 12, Table 9) whereas it would be expected to enter only valve No. 2. Other differences will be seen between the computed and the observed temperatures of the water issuing from the showers due to the unexpected manner in which the hot and the cold water mix. In computing the temperatures given in the tables no allowance has been made for the effect of the difference of velocity of flow in the hot-water and the cold-water supply pipes, respectively. The effect of this factor will be most markedly shown where the quantities of hot water and cold water are different, as in Tables 9 and 11.

The conclusions reached from these tests are:

(1) It is not possible to install a battery of shower baths with manually controlled valves at each shower without danger of scalding the bathers. If there is no check valve in the cold-water supply line to each shower scalding water may enter the shower through the cold-water supply line.

(2) The use of large supply mains, with high loss of head between the main and the control valve, will aid in maintaining a constant temperature at each shower head. It will not remove all danger from scalding.

Where the flow of water from a shower head placed in a battery of showers or on a plumbing system where other fixtures are connected is in the hands of the bather the only assurance against scald-

TABLE 12

SHOWER MIXING VALVES TESTED

Test Curves Number in Figs. 20 to 25	Pipe Sizes, in.		Control	Can Hot Water Enter Through Cold-Water Pipe
	Inlet	Outlet		
1	½	½	Automatic Mechanical	Yes
3	½	½	Automatic Thermostatic	No
7	1	1¼	Automatic Thermostatic	No
2	¾	¾	Manual	Yes
6	½	½	Manual	Yes
5	½	½	Manual	Yes
4	½	½	Manual	Yes

ing is through the use of a properly designed mixing valve placed at the shower so as to be controlled by the bather. A mixing valve depending on the action of a balanced piston to maintain a constant difference of pressure between the hot-water and the cold-water supply, together with check valves placed on the cold-water supply pipes of each shower, or a thermostatically controlled mixing valve were found to be dependable in preventing the issue of scalding water from the shower.

15. *Shower Bath Mixing Valves.*—The temperature of the water of a shower bath can be controlled, within the limits of the temperatures of the hot-water and cold-water supplies, by means of a properly designed mixing valve placed on the pipe leading to the shower head. In order to determine the effectiveness of shower mixing valves available on the market tests were made on the valves listed in Table 12.

The requisites of a good mixing valve include the following:

(1) The ability to prevent a sudden discharge of water at a scalding temperature.

(2) The ability to maintain a constant temperature at the shower regardless of fluctuations of temperature or pressure in the hot-water and cold-water supply pipes.

(3) The temperature at the shower should change in proportion to the change of position of the control handle on the valve. The temperature should not make sudden changes but should progress smoothly from cold to hot or from hot to cold.

TABLE 13

DISCHARGE RATES FROM PROPRIETARY SHOWER HEADS AND NOZZLES USED IN TEST

Pressure at Base of Shower Head or Nozzle ft. of water	Discharge Rate gal. per min.	Pressure at Base of Shower Head or Nozzle ft. of water	Discharge Rate gal. per min.	Pressure at Base of Shower Head or Nozzle ft. of water	Discharge Rate gal. per min.	Pressure at Base of Shower Head or Nozzle ft. of water	Discharge Rate gal. per min.	Pressure at Base of ShowerHead or Nozzle ft. of water	Discharge Rate gal. per min.	Pressure at Base of ShowerHead or Nozzle ft. of water	Discharge Rate gal. per min.
⅜-in. Nozzle		⅝-in. Nozzle		4-in. Shower Head No. 1		4-in. Shower Head No. 2		6-in. Shower Head (Store Room)		0.955-in. Nozzle	
7.2	6.0	2.1	9.6	2.5	4.5	32.2	15.1	7.2	15.4	2.1	20.8
12.2	7.7	7.7	18.4	9.5	8.5	43.9	18.2	12.2	19.7	4.2	28.8
32.2	12.4	14.4	24.7	17.9	11.9	68.2	21.9	27.2	28.9	7.6	38.7
47.2	14.9	30.1	35.7	27.4	14.3	115.3	27.5	47.2	37.6	14.15	52.1
68.8	18.0									27.6	73.5
91.0	20.7										

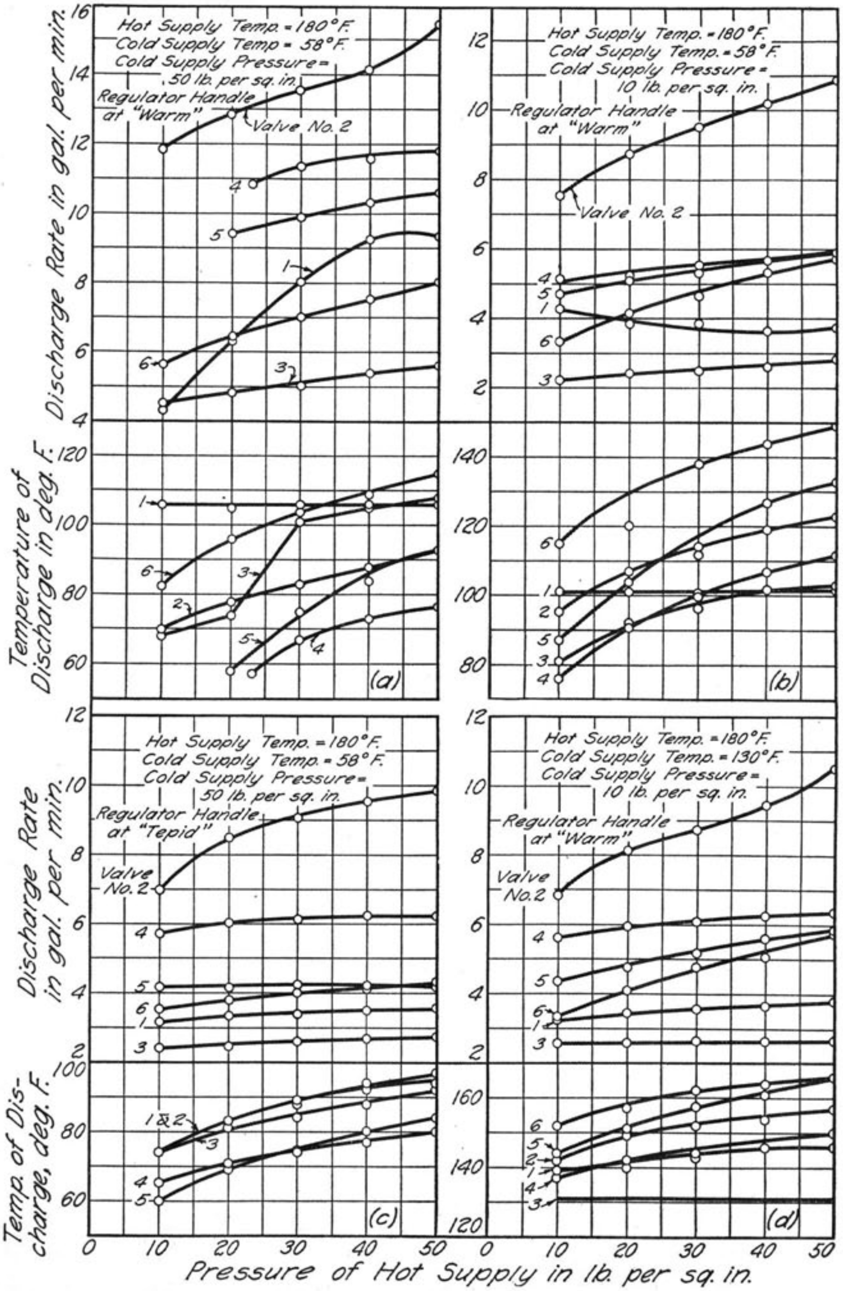

Fig. 20. Shower Bath Mixing-valve Tests

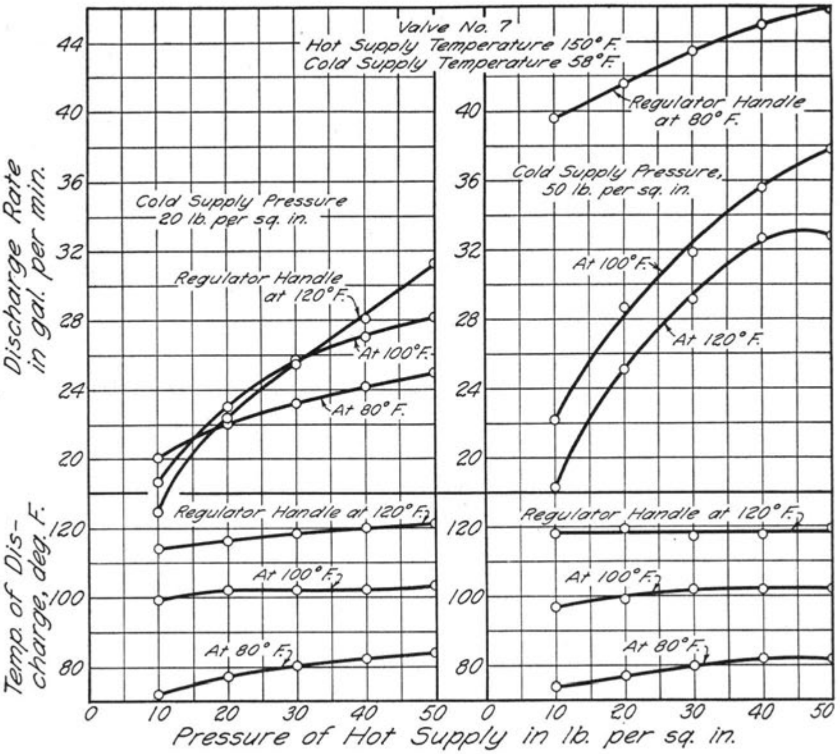

FIG. 21. SHOWER BATH MIXING-VALVE TESTS

(4) The adjustment of the temperature should be simple and accurate. The temperature of the shower should be the same for any particular position of the valve handle, assuming that the temperatures of the hot-water and the cold-water supplies do not change.

(5) The loss of head through the mixing valve should be low.

Each of the proprietary valves listed in Table 12 was tested for the conditions stated. The apparatus used for testing a mixing valve is shown in Fig. 18. The temperatures and pressures of the hot and the cold water were controlled and measured in the same manner as in the tests on a battery of showers, as described on page 42. Pressure gages were placed on the branch cold-water and hot-water pipes immediately above the mixing valve, and a pressure gage was attached to the shower head immediately above the shower head or the calibrated orifice substituted therefor.

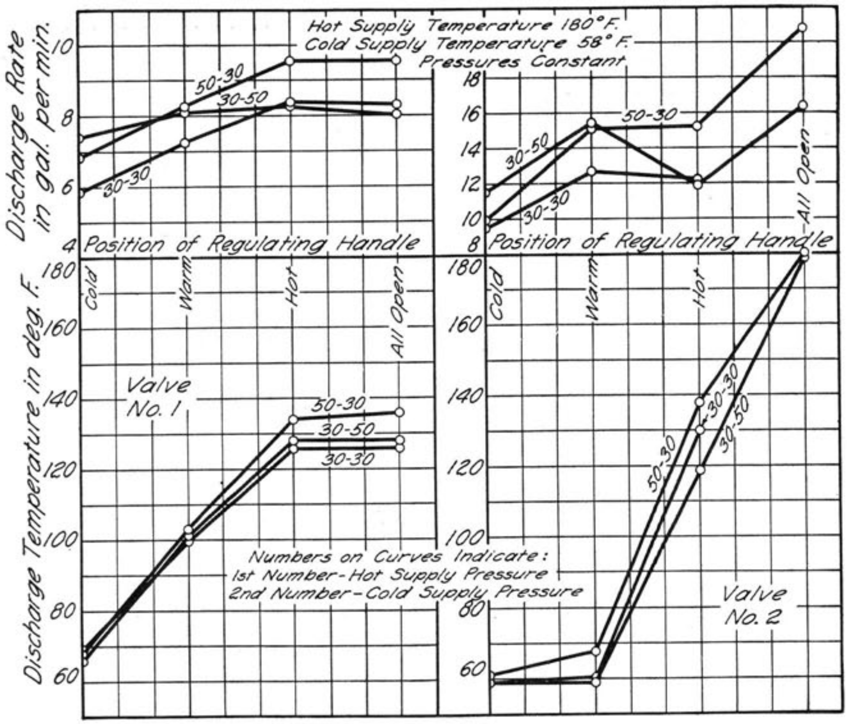

FIG. 22. SHOWER BATH MIXING-VALVE TESTS

Preliminary tests were made to determine approximately the rate of discharge and the pressures for proper operation of shower heads. It was found that when the pressure at the shower head exceeded about 5 lb. per sq. in. the spray struck the body with an uncomfortable stinging sensation. At about 20 lb. per sq. in. some of the proprietary shower heads failed by bursting. The capacities of three shower heads and three of the calibrated orifices used in the tests are given in Table 13.

The procedure in testing the shower mixing valves listed in Table 12 was as follows:

The valve to be tested was set in position and two different sets of observations were then taken:

First, all conditions were held constant except the pressure of the hot-water supply. As the pressure of the hot-water supply was varied the temperature and the rate of discharge were observed. These tests were repeated with different temperatures of hot water and of cold water.

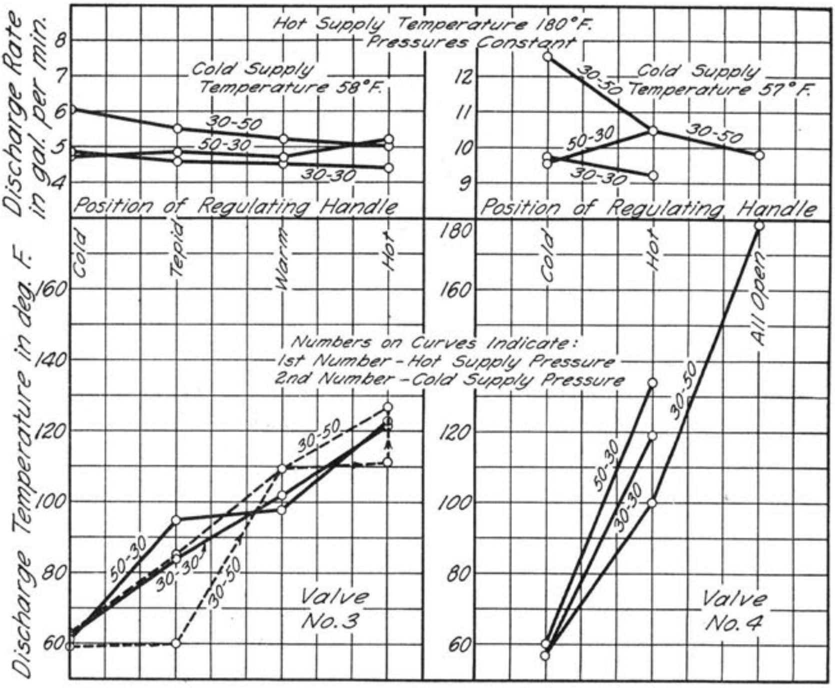

FIG. 23. SHOWER BATH MIXING-VALVE TESTS

Second, all conditions were held constant except the position of the regulating valve. This was moved to different positions and the temperature and pressure of the discharge were observed.

Some results of the first series of tests are shown graphically in Figs. 20 and 21, and of the second series in Figs. 22 to 25.

It is concluded from a study of these results that none of the mixing valves tested will fully satisfy all of the conditions listed on pages 44 and 47.

Valve No. 1 shows the greatest ability to maintain a constant temperature at the shower, regardless of fluctuations in the pressure of the hot-water supply. This is shown by curve No. 1. in Fig. 20. Under the conditions shown in Figs. 20a and 20b the temperature at the shower is practically constant. Under the conditions shown in Fig. 20c, with the regulating handle at "tepid," all of the valves tested showed approximately the same variations in temperature. Under the conditions shown in Fig. 20d, in which the temperature of the cold-water supply is 130 deg. F., valve No. 1 is holding the temperature at the shower fairly constant and valve No. 3 is holding

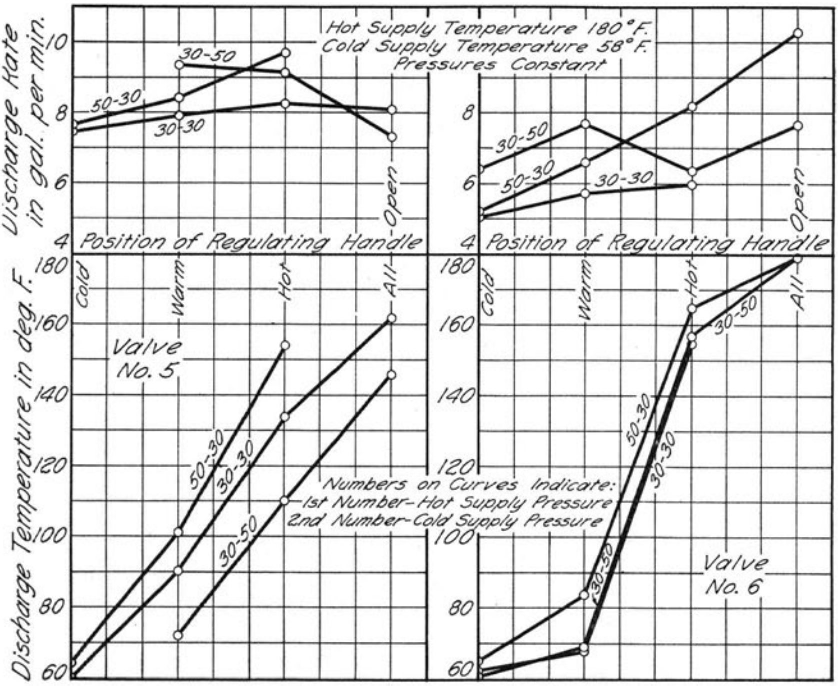

Fig. 24. Shower Bath Mixing-valve Tests

it absolutely constant. This test is particularly significant as it is desired to prevent the passage of hot water into the shower through the cold-water supply pipe. It is evident that only a thermostatically controlled valve will do this.

The ability to prevent a sudden discharge of hot water through the shower is not demonstrated certainly by any valve tested. Valve No. 1, in which the control depends upon the action of a balanced valve, maintains an almost constant temperature under the conditions of the test. Its construction shows, however, that if there is a change of temperature of hot water without a change of pressure, which is improbable, or if there is a sudden discharge of hot water through the cold-water pipe, which is probable, the action of the valve would not prevent the scalding of the bather.

Thermostatically controlled valves, such as Nos. 3 and 7, offer the greatest promise of satisfactory results. Unfortunately, the mechanism of these valves did not operate accurately and in some cases wide variations of temperature occurred. This was due possibly to the sticking of the mechanism or to sluggish action. The speed

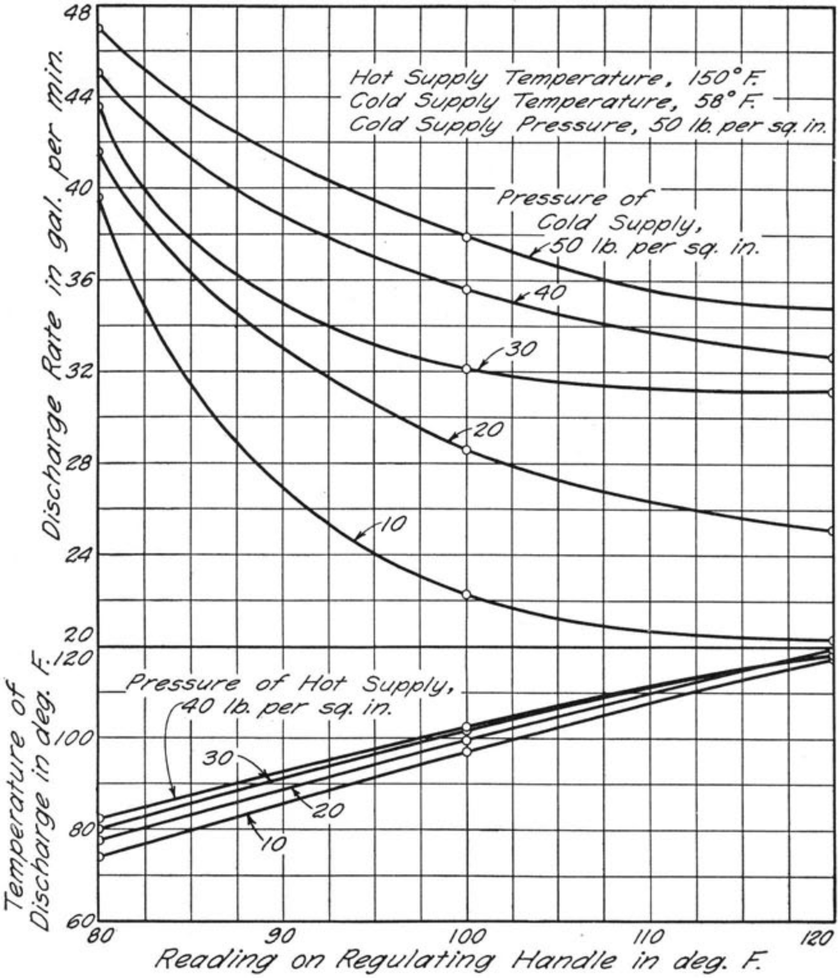

Fig. 25. Shower Bath Mixing-valve Tests

of change of temperature of the water issuing from a shower head is dependent upon the speed with which the temperature of the water supply is changed. If this change is instantaneous, as it may be, then the temperature at the shower head will change instantaneously. A thermostatically controlled valve must, therefore, have a reservoir to hold water momentarily to give the mechanism of the valve time to respond to a temperature change, and to close the proper ports.

The ability of all valves to vary the temperature at the shower according to the position of the valve handle was demonstrated satisfactorily. Valve No. 3 gave some trouble as a result of sticking of the mechanism. This is shown in Fig. 23a. Another valve of the same type, No. 7, gave satisfactory results, as is shown in Fig. 25.

Probably among the least important of the requirements listed on pages 44 and 47 is that the loss of head through the valve should be small. Those valves which show the best temperature control require the greatest amount of head for their operation. This is shown in Fig. 20.

It is finally concluded that where a sudden increase in the temperature of the cold-water supply cannot occur, either a pressure controlled valve, such as No. 1, or a thermostatically controlled valve, such as Nos. 1 and 7, will prove satisfactory in maintaining a constant temperature at the shower head. Where a sudden increase of the temperature of the cold-water supply may occur only a thermostatically controlled valve with proper mechanism is safe.

V. TESTS ON PLUMBING SYSTEM OF A TALL BUILDING

16. *Plumbing Test in Ridgley Farmers State Bank Building.*—The Ridgley Farmers State Bank Building in Springfield, Illinois, is a 13-story office building which was erected early in 1927. An opportunity was offered of making certain tests upon the plumbing of this building during its erection. The principal purposes of the tests included an attempt to show the effectiveness of and the need for complete systems of venting in the plumbing of tall buildings; an attempt to show the relation between the pressures and rates of discharge in tall stacks; an attempt to determine the greatest possible rate of discharge down the stacks in a plumbing system; and an attempt to determine the relation between the height of fall in a vertical pipe and the pressure produced in it. It was expected that the tests might reveal also some new facts concerning the venting of plumbing systems, and that other data of value might result from tests conducted under other than laboratory conditions. The value of the results obtained, as adding to data already obtained, or revealing new facts, was disappointing.

The desired purposes were not all accomplished. The effectiveness of venting was shown conclusively. The relation between the pressure and the rate of discharge in tall stacks was not found with accuracy. The fact that there is some relation was developed, and it was shown that both back pressure and siphonage increase with the rate of discharge. The definite relation, which is stated in Bulletin No. 143, was neither corroborated nor disproved. The minimum rate of discharge which would create an excessive pressure in the 5-in.

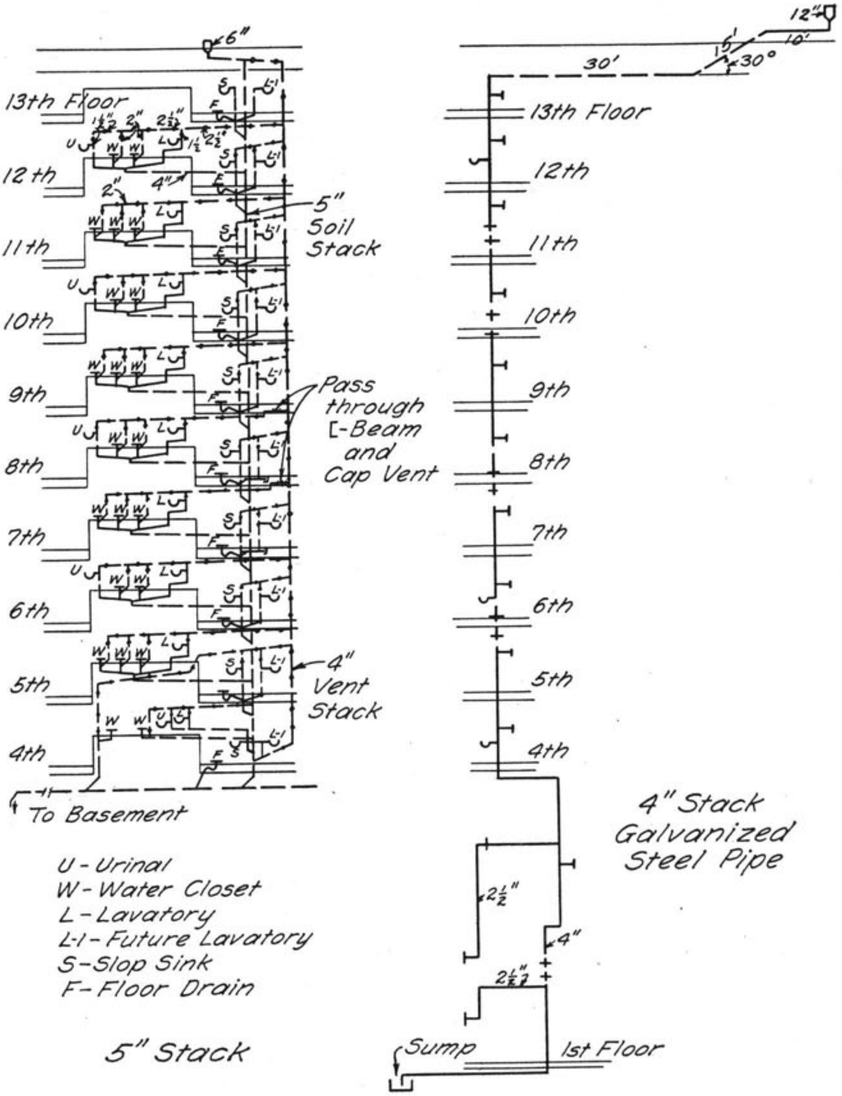

FIG. 26. PIPING CONNECTIONS TO 5-IN. AND 4-IN. STACK IN RIDGLEY FARMERS STATE BANK BUILDING

soil stack was shown to be about 500 gallons per minute. The conditions of this test were more severe than would ordinarily be met with in practice, so that greater rates of discharge may be used, under other conditions, with satisfaction. No information of value was obtained on the relation between pressures and height of fall of water in a vertical pipe.

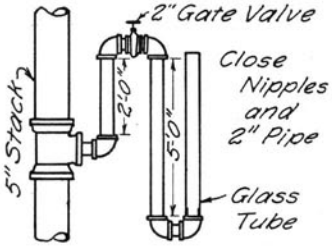

FIG. 27. PIEZOMETER CONNECTIONS TO 5-IN. STACK IN RIDGLEY FARMERS STATE BANK BUILDING

17. *Piping Arrangement.*—The total height of the building, from basement to roof, is 181 ft. 10 in. The vertical pipes or stacks of the plumbing system are grouped in pipe runs. These vertical pipes are of various sizes, from 1¼ in. up to, and including, 5 in. They are used for various purposes, including soil pipes, waste pipes, fire risers, water supply, and heating. All riser pipes change from the vertical to the horizontal at the fourth floor in order to pass over the lobby of the offices of the bank. The vertical length of the pipes above the fourth floor is 115 ft. 10½ in. This height is the effective height of pipe for testing purposes, as the change in direction at the fourth floor has an effect similar to that of a house drain.

18. *The 5-in. Stack.*—Tests were conducted on portions of two vertical pipes above the fourth floor, one a 5-in. soil stack, to which approximately 3 water closets, 1 urinal, 1 slop sink, 1 lavatory, and 1 floor drain were to be attached at each floor. All of the fixtures to be connected to this stack will be vented by loop or continuous vents. All branch vents were connected to the same vent stack which was reconnected to the 5-in. soil stack just below the roof. A diagram of this pipe with its connections above the fourth floor is shown in Fig. 26. An offset of about 9 inches, which is made up of two 45-deg. bends and a nipple, occurs between the 9th and 10th floors. The presence of this offset materially affected the results of the tests and prevented the use of this stack for the purpose of showing anything of more general value than the effectiveness of venting.

19. *The 4-in. Stack.*—The other stack on which tests were made consisted of a 4-in. galvanized steel pipe with a tee at each floor. This pipe is installed in the building as a fire riser. Special connections were made at the roof and in the basement so that water could be poured in at the top, and would be discharged into a sump in the basement. The connections to this pipe are shown in Fig. 26. The

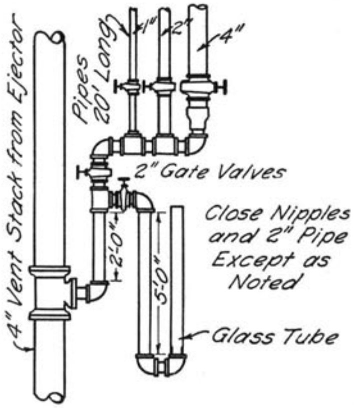

FIG. 28. CONNECTIONS TO 4-IN. STACK IN RIDGLEY FARMERS STATE BANK BUILDING

vertical length of the pipe above the fourth floor is approximately 114 feet.

20. *Pressures Measured.*—Pressures were measured in the 5-in. stack at the 4th and at the 12th floors, and in the 4-in. stack at the 4th, the 6th, and 12th floors. The pressures were measured by observing the movement of water in one leg of a glass U-tube connected as shown in Fig. 27. This method of measuring pressures in plumbing systems is described in detail on pages 15 and 16 of Bulletin No. 143. When the pressures were being measured on the 5-in. stack the openings to all fixtures and traps were closed except in one instance in which the seal on the floor drain on the 12th floor was tested.

21. *Venting.*—Venting on the 5-in. stack is shown in Fig. 26, and the arrangement of venting the U-tubes or traps on the 4-in. stack in Fig. 28. The arrangement of pipes and valves on the 4-in. stack made possible tests without a vent, and also tests with either a 1-in., a 2-in., or a 4-in. vent, each about 20 feet long.

22. *Method of Discharging Water into Stacks.*—Water was discharged into either the 5-in. or the 4-in. stack from a tank placed on the roof. The tank was 4 ft. in diameter and 4 ft. deep. One 4-in. and one 3-in. circular flanged opening were cut in the bottom of the tank and quick-moving gate valves of the corresponding sizes were connected to the flanges. The rate of discharge was determined by measuring the distance the water dropped in the tank during the seven-second period that either or both the valves

TABLE 14

PRESSURES OBSERVED IN 5-IN. SOIL STACK*

Pressures at 12th Floor		Pressures at 4th Floor			
Rate of Discharge gal. per min.	Pressure ft. of water	Rate of Discharge gal. per min.	Pressure ft. of water	Rate of Discharge gal. per min.	Pressure ft. of water
227	−0.30	227	−0.18	525	−0.24
260	−0.28	227	−0.20	525	−0.32
309	−0.24	260	−0.24	608	−0.26
608	−0.32	260	−0.24	835	−0.22
608	−0.46	309	−0.22	835	−0.30
835	−0.46	405	−0.34	915	−0.42
915	−0.70	405	−0.36		
915	−0.50				

*Pressures are expressed in feet of water and are computed by multiplying by 2 the observed maximum movement of water in one leg of the piezometer. Inaccuracies up to about 10 per cent enter into this method because of the irregularities in diameters of the two legs of the piezometer. The sign − before a pressure indicates less than atmospheric pressure, or siphonage. The sign + before a pressure indicates greater than atmospheric pressure or back-pressure.

were held open during a test. By using either the 3-in. or the 4-in. valve, or a 2-in. nipple connected to the 3-in. valve, and different depths of water in the tank, rates of discharge between 100 and 900 gallons per minute were obtainable.

The water fell from the valves for a short distance, freely through the atmosphere, into a funnel placed on top of the stack to receive it. For the higher rates of discharge the stack would not take the water as fast as it was delivered from the tank until the funnel had filled sufficiently to cover the top of the stack with a substantial water seal. The suction created in the stack would then draw the water into it from the funnel. It is probable, therefore, that pressures produced by high rates of discharge were obtained under conditions different from those for pressures produced by low rates of discharge. An attempt to express the relation between the rate of discharge and the pressures created for all rates of discharge used might, therefore, result in misleading conclusions. The importance of developing a method of discharging water into a stack in a manner which can be controlled and duplicated is thus emphasized.

23. *Conditions at Top of Stacks.*—The conditions at the top of both the 5-in. and the 4-in. stacks were such as to make it impossible to apply the results of these tests to other plumbing stacks. The 5-in. stack protruded about 15 in. above the roof. It turned horizontally beneath the roof for a distance of about 12 feet and then turned to drop vertically to the 4th floor. At this turn the vent stack is connected to the 5-in. soil stack. Hence, in discharging

TABLE 15

PRESSURES OBSERVED IN 4-IN. STACK AT 12TH FLOOR*

Rate of Discharge gal. per min.	Pressure in Feet of Water With and Without Vents		
	No Vent	1-in. Vent	4-in. Vent
102	−0.56	−0.28	......
227	−2.16	−1.30	−0.36

*See note under Table 14.

TABLE 16

PRESSURES OBSERVED IN 4-IN. STACK AT 4TH FLOOR*

No Vent

Rate of Discharge gal. per min.	Pressure ft. of water	Rate of Discharge gal. per min.	Pressure ft. of water	Rate of Discharge gal. per min.	Pressure ft. of water
102	+1.28	172	+2.84	309	+3.02
126	+1.72	227	+2.00	355	+5.64
150	+2.14	260	+2.90	525	+10.00

*See note under Table 14. Each of the pressures recorded in this table represents an average of 5 or more observations under similar conditions.

TABLE 17

PRESSURES IN 4-IN. STACK AT 4TH, 6TH, AND 12TH FLOORS*

No Vent

Rate of Discharge gal. per min.	Pressure in Feet of Water		
	4th Floor	6th Floor	12th Floor
102	+1.28	−2.20	−0.56
126	+1.72	−1.74	......
150	+2.14	−1.62	......
174	+2.84	−2.28	......
227	+2.00	......	−2.16

*See note under Table 14. The pressures recorded in this table, except those on the 12th floor, represent an average of 5 or more observations under similar conditions.

water at a high rate into the soil stack, proper venting was restricted, and might even be cut off by the water in the soil stack. The result would be a material change from the pressures normally found in the stack when the vents were unobstructed.

The conditions at the top of the 4-in. stack are shown in Fig. 26. The top of the stack was choked with water at practically all rates of discharge, and the rate of discharge down the stack was ma-

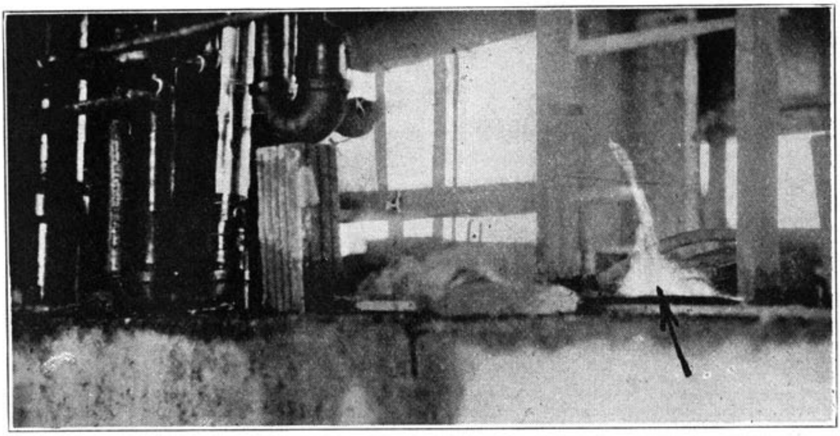

FIG. 29. WATER LEAPING INTO AIR FROM FLOOR DRAIN ON 12TH FLOOR OF RIDGLEY FARMERS STATE BANK BUILDING

terially affected by the intensity of vacuum created, and the moments at which the vacuum appeared during a test.

24. *Tests on Soil Stacks.*—The following tests were made:

(1) On the 5-in. stack pressures were observed at the 12th floor for rates of discharge between 227 and 915 gallons per minute. The results are shown in Table 14.

(2) On the 5-in. stack pressures were observed at the floor drain on the 12th floor for a rate of discharge of 900 gallons per minute. The water first blew up into the air about 18 inches, and, on its falling back into the drain, the trap was sucked empty, leaving the seal uncovered. A view of the water jumping into the air is shown in Fig. 29.

(3) On the 5-in. stack pressures were observed at the 4th floor for rates of discharge of from 227 to 915 gallons per minute. The observed pressures are given in Table 14.

(4) On the 4-in. stack pressures were observed at the 12th floor with no vent, a 1-in. vent, and a 4-in. vent, for two rates of discharge, 102 and 227 gallons per minute, respectively. The observed pressures are given in Table 15.

(5) On the 4-in. stack pressures were observed at the 4th floor, with no vent, a 1-in. vent, and a 4-in. vent, for various rates of discharge. No observations were recorded quantitatively. It was evident that the vents were very effective in diminishing the observed pressures. A 4-in. vent reduced the

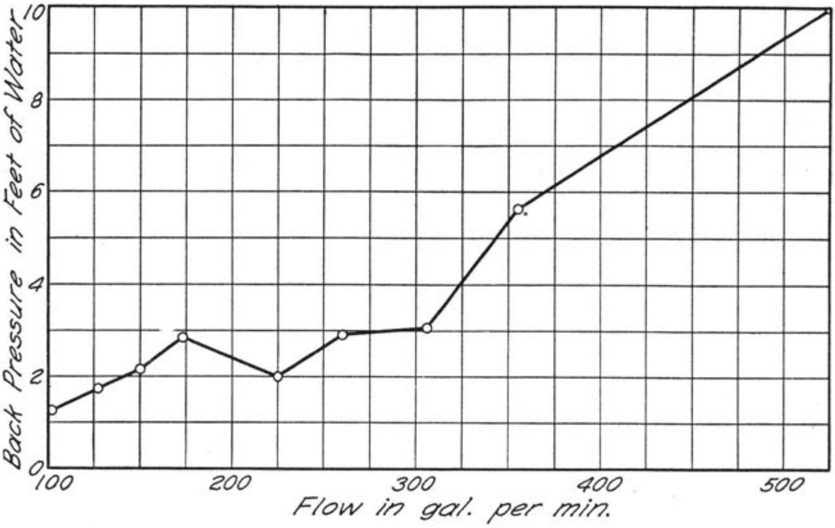

FIG. 30. BACK PRESSURE IN 4-IN. STACK, WITHOUT VENT, AT 4TH FLOOR OF RIDGLEY FARMERS STATE BANK BUILDING

movement of the water in the U-tube from two or three feet to one and one-half to two inches.

(6) On the 4-in. stack pressures were observed at the 4th floor, for rates of discharge of from 102 to 525 gallons per minute. The observed pressures are given in Table 16 and plotted in Fig. 30.

(7) On the 4-in. stack pressures were observed at the 6th floor with no vent, at rates of discharge of 102, 126, 150, and 174 gallons per minute, respectively. The observed pressures are given in Table 17.

25. *Results of Tests on Soil Stacks.*—The tests made on the 5-in. soil stack, the results of which are recorded in Table 14, indicate that rates of discharge above 500 gallons per minute may produce undesirable pressures in a 5-in. soil stack installed under the conditions of the test; and that lower rates of discharge should not produce undesirable conditions. A discharge of 500 gallons per minute is equivalent to the simultaneous discharge of about 12 water closets. The venting provided with this stack is effective in minimizing the pressures.

The tests made on the 4-in. soil stack, the results of which are recorded in Tables 15, 16, and 17, indicate that vents are equally effective in reducing both back pressure and siphonage, and that, with proper venting, about 200 gallons per minute, a rate equivalent to the simultaneous discharge of about 5 water closets, can be discharged down a 4-in. stack 100 ft. high, arranged as shown in Fig. 26. This capacity might be increased by the use of a long sweep fitting at the fourth floor to change from the vertical to the horizontal, and by the use of by-pass venting.

An additional conclusion is that pressures in a tall stack increase with the rate of discharge. Insufficient observations were made to render possible a quantitative statement of this relation, or to corroborate or disprove the conclusion reached in Bulletin No. 143 that the pressure varies as the five-halves power of the height.

VI. CONCLUSIONS

26. *Summary of Conclusions.*—Probably the most important conclusion reached as a result of these tests, from the viewpoint of immediate practical applicability to the design of plumbing for tall buildings, is that, by the use of a by-pass vent stack, and a proper connection at the base of a stack, all pressures in a plumbing system caused by water falling down the stack can be very materially reduced, in some cases to less than 5 per cent of the pressures developed under existing accepted practice. This is shown in Table 6, where the pressure at the second floor in a plumbing system having a 3-in. manifold by-pass vent stack is shown to be only 5 per cent of the pressure at the same floor when the stack is open only at the top and bottom. The use of a long radius bend at the lower end of a stack is shown in Table 5 to result in pressures markedly less than those occurring when other types of fittings are used.

The relative strengths of various forms of traps tested to resist siphonage are given in Table 2. The results presented in this table indicate that the non-siphon interior-baffle hair-pin 1¼-in. trap shown in Fig. 7a had the strongest seal, and a built-up 1½-in. P trap the weakest.

The following general conclusions are listed in the order in which the tests made are reported:

(1) The strength of the seal of a trap is directly proportional to the depth of the seal of the trap.

(2) There is less difference between the relative strengths of different types of traps in resisting repeated applications of siphonage than in resisting a single application. The seal of the best non-siphon trap tested under repeated applications of si-

phonage was broken with only twice the strength of siphonage necessary to break the seal of a simple P trap. Under repeated applications of siphonage an ordinary drum trap is as effective a non-siphon trap as the best of the patented proprietary non-siphon traps tested.

(3) It usually requires a greater intensity of back pressure than of siphonage to break the seal of a trap. On account of the effect of the type of fixture and the arrangement of the waste pipe above the trap it is impracticable to make a comparison of the relative strengths of different types of traps to resist seal rupture by back pressure.

(4) The relative order of strength of seal to resist self-siphonage in standard lead traps is running, bag, P, and S, the running traps having the strongest seal.

(5) An increase in the length of either the vertical or the horizontal portion of the waste pipe, up to a certain limit, causes less water to be left in a trap after the discharge of the fixture to which it is attached. This renders easier the breaking of the trap seal by air pressure.

(6) The point at which an increase in the length of the waste pipe will not cause a decrease in the water left in the trap after the discharge of a fixture is reached when the friction becomes great enough to reduce the maximum flow which can pass through the trap.

(7) It is possible to select a size and type of trap which cannot lose its seal from self-siphonage if the rate of discharge from the fixture and the arrangement of the waste pipes are within the limits of those used in obtaining the results recorded in Table 4.

(8) The seal of none of the non-siphon traps tested, including the drum traps, could be broken by self-siphonage under conditions of maximum rate of flow through the trap.

(9) In unvented waste pipes siphonage is transmitted with practically undiminished intensity. A trap located near the source of siphonage in such a case is subjected to as great a negative pressure as one far removed from the source. When the waste pipe is well vented a greater intensity of siphonage is required to break the seal of a trap located near the vent than to break the seal of one far from the vent. No practicable limit can be set as to the maximum permissible distance of a trap from a vent; this depends on many factors in the design of the plumbing system to which the trap is connected. In general

it is desirable that a vent be placed as close as possible to the trap it is to serve.

(10) A long-sweep 90-deg. elbow is the most effective type of connection at the lower end of a stack to diminish pressures produced in the plumbing system. The relative effectiveness of other types of connections is shown in Table 5.

(11) The use of by-pass venting will reduce the pressures produced in a plumbing system by from 50 to 95 per cent as compared with the pressures which may occur without by-pass venting.

(12) Compression faucets have only one-half the capacity of ground key faucets. The actual capacities of the faucets tested are given in Table 7.

(13) It is not possible to design the piping system for a battery of shower baths so as absolutely to prevent the possibility of the scalding of a bather. The safety of a bather in this respect can best be assured by the use of proper mixing valves under the bather's control.

(14) Where the conditions are such that a sudden increase in the temperature of the cold-water supply cannot occur either a pressure-controlled or a thermostatically-controlled valve will maintain a constant temperature at the shower head; where a sudden increase in the temperature of the cold-water supply is possible only a thermostatically-controlled valve with proper mechanism is safe. None of the standard mixing valves tested was found to completely satisfy the requirements of such a valve as listed on pages 44 and 47.

(15) The tests made on the 5-in. stack in the Ridgley Farmers State Bank Building (see page 52 *et seq.*) indicate that rates of discharge above 500 gallons per minute (a rate equivalent to the simultaneous discharge of about 12 water closets) may produce undesirable pressures in a 5-in. stack installed under conditions similar to those of the test; and that a lower rate of discharge should not produce undesirable conditions.

(16) The tests made on the 4-in. stack in the same building indicate that vents are equally effective in reducing both back pressure and siphonage; and that, with proper venting, about 200 gallons per minute (a rate equivalent to the simultaneous discharge of about 5 water closets) can be discharged down a 4-in. stack 100 ft. high, arranged as in the test. This capacity might be increased by the use of a long-sweep fitting at the lower end of the stack, and by the use of by-pass venting.

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