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TESTS ON THE HYDRAULICS AND PNEUMATICS OF HOUSE PLUMBING

BY

HAROLD E. BABBITT

BULLETIN NO. 143

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ENGINEERING EXPERIMENT STATION

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BY

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TESTS ON THE HYDRAULICS AND PNEUMATICS OF HOUSE PLUMBING

I. Introduction

1. *Purpose and Scope.*—The tests herein reported were undertaken with a view of obtaining definite information concerning the positive and negative pressures found in soil-stacks, waste pipes, traps, and vent pipes, and also concerning the limitations of rates of discharge and the capacities of waste pipes and soil-stacks.

The investigation thus involved a consideration of the hydraulics and pneumatics of different parts of plumbing systems. In the tests various diameters, lengths, and arrangements of pipes, traps, and vents were used. The discharges, velocities, and pressures were varied in such a way as to permit the study of the actions under a variety of conditions.

The study was directed primarily toward the solution of problems connected with the design of waste and vent pipes for a one-, two-, or three-story residence. In the course of the tests other information applicable to plumbing design has been gathered, and some of the data and conclusions are as applicable to tall buildings as to residences. It is believed that the results of the tests and the principles established will be helpful when making designs of plumbing installations, and in reducing the complication and cost of plumbing work.

The principal problems studied were the proper type and capacity of vents for various conditions, the causes of and methods of preventing self-siphonage of traps, the capacity of soil-stacks, and the effect on the pressures in a plumbing system resulting from (a) closing the top of the soil-stack, (b) mixing solid matter with the discharge from water-closets, (c) changing the length of the horizontal pipe in the basement to which the soil-stack is connected, (d) changing the height of fall in the soil-stack, (e) changing the rate of discharge, (f) the use of a house-trap, and (g) submerging the outlet from the plumbing system, as may happen when the water in the street sewer rises above the outlet of the house-sewer or when roof water, discharging into the house-drain, overcharges it.

The tests reported herein were carried on as part of the work of the Engineering Experiment Station, the work being done in the Department of Theoretical and Applied Mechanics and Municipal and Sanitary Engineering.

2. *Plumbing Investigations.*—The first apparatus for making plumbing tests at the University of Illinois was installed in 1910. This apparatus was used for about two years but none of the observations made or conclusions drawn from its use has been published. The present series of tests was begun in February, 1919. In 1922 additional impetus was given to the progress of the work by the interest displayed by the Illinois Master Plumbers Association which has donated material and given financial aid. Preliminary reports on the progress of the tests were presented at the annual conventions of the Association in 1922 and 1923.

After the manuscript for this bulletin had been prepared, the report "On the Siphonage of Traps," by George E. Waring, Jr., E. S. Philbrick, and E. W. Bowditch, printed in the Report of the National Board of Health for 1882, was read. The objective of this investigation was apparently to compare the effectiveness of different types of traps—not to study the causes of the movement of water in the traps. The apparatus used in the tests was similar to that used at the University of Illinois and the results are in agreement whenever the conditions were the same.

In 1921, A. E. Hansen published a book, "Plumbing Fixture Traps," which is mainly an account of tests on traps alone, conducted in New York City. The book also contains a comprehensive review and résumé of investigations of a similar nature made from 1881 to 1890. Since the latter date little has been published on the results of tests, but apparently many tests have been made. In the book references are given to publications in which earlier tests have been reported and to discussions of results of subsequent tests.

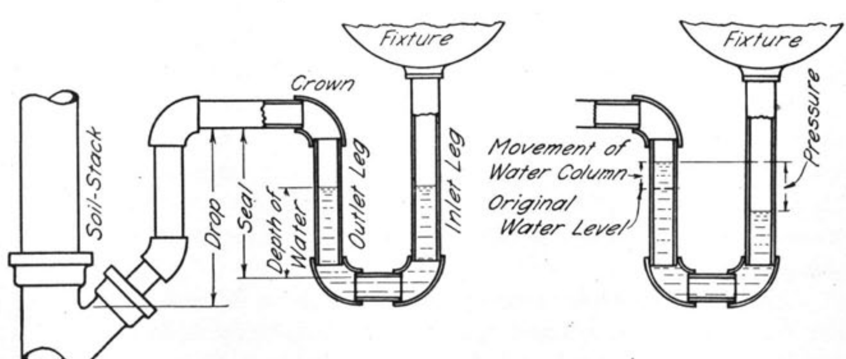


FIG. 1. TRAP AND CONNECTIONS

The first report of the Sub-committee on Plumbing of the Building Code Committee of the Department of Commerce, made in September, 1922, contains a brief account of tests conducted to determine the effect on the seals in traps resulting from the discharge of water through fixtures and pipes to which the traps were connected.

3. *Terms.*—The following are definitions of a few of the technical terms as used in this bulletin. The use of these terms has not been standardized in plumbing practice and it is recognized that the definitions which follow may not be in agreement with the sense in which the terms are used under some conditions.

A trap is a fitting in which water is retained to prevent the free passage of air. The various parts of a simple trap are illustrated in Fig. 1. This represents the type of trap used in these tests.

Positive pressure is pressure above atmospheric. This is sometimes called back-pressure.

Negative pressure is pressure below atmospheric. It is sometimes called vacuum.

Self-siphonage is the action which creates negative pressure in a trap as the result of water passing *through* the trap.

A crown vent is a vent at the crown of a trap. It is illustrated in Fig. 2.

In a continuous waste and vent the vent pipe is a continuation of the vertical portion of the waste pipe, as shown in Fig. 2; this vent is usually called a continuous vent.

A loop vent or circuit vent is a continuation of the horizontal portion of a waste pipe beyond the connection with the discharge pipe from a

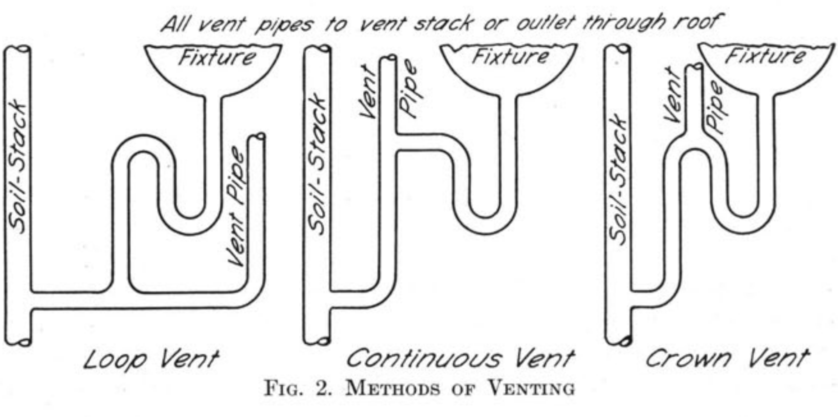


FIG. 2. METHODS OF VENTING

fixture. The extended pipe turns vertically as the vent pipe. It is illustrated in Fig. 2. In a loop or circuit vent the pipe which serves as a waste for one or more fixtures acts also in part as a vent; the continuation of this pipe beyond the connection with the discharge pipe of the fixture farthest from the soil-stack serves as a vent only. A form of loop vent used in the tests is shown in Fig. 2.

A soil-stack is a vertical pipe which takes the discharge from plumbing fixtures; it connects with the house-drain.

A horizontal waste or soil pipe is here called a waste pipe. It slopes slightly in the direction it discharges and receives the discharge from all kinds of fixtures.

The seal of a trap is the shortest vertical distance which water must rise to pass through the trap, as shown in Fig. 1.

The drop in the outlet from a trap is the vertical distance between the upper level of the seal of the trap and the top of the junction of the waste pipe with another waste pipe that is large enough to prevent the formation of negative pressure at the junction, as shown in Fig. 1.

A house-drain is a waste pipe into which the soil-stacks discharge; it usually slopes ¼-in. to the foot, or more. The house-drain connects with the house-sewer or street-sewer outside of the wall of the building.

A house-sewer is the pipe which begins outside of the wall of the building and connects the house-drain with the public sewer in the street.

4. *The Phenomena of Flow through Plumbing Pipes.*—A brief discussion concerning what occurs when plumbing fixtures are emptied into the pipes of a plumbing system, read in advance of the description of the tests, may be helpful. It is to be expected that the manner of flow through plumbing pipes will differ from that through either water-supply pipes or sewers. The flow is intermittent. In the horizontal waste pipes the cross-section of the pipe may or may not be filled with water. It is not to be expected that the flow down the soil-stack will be the same as that found when water feeds freely into the top of a vertical pipe in such a way that the pipe flows full, as in the case of a down-spout supplied with an abundance of water. Instead, at least in the case of the discharge of as much water as will come from a water-closet, the first of the water to reach the soil-stack from a horizontal waste pipe will have fallen some distance and gained considerable velocity before the last of the discharge of the fixture reaches the soil-stack. As a result air from the upper part of the soil-stack is carried down with the discharging water, and the space in the soil-stack occupied by the dis-

charging water and the entrained air is greater than that which would be taken by the water alone in a compact body.

The water and air in such a case occupy the full section of the soil-stack and move down together and act somewhat as a long elastic piston in expelling air ahead of the discharge and in drawing in air behind it. The presence of air intermingled with the falling water allows parts of this piston to expand somewhat or to be compressed slightly according as the water at the head of the piston is accelerated or retarded, and thus negative or positive pressures are created which may be transmitted to tributary waste pipes and traps. The negative pressure may be expected to develop when the first of the falling water has had sufficient opportunity to acquire a greater velocity than that of the water following it, and the positive pressure when the velocity of the leading water is retarded, as at the time it reaches the bottom of the soil-stack. If there is no unvented house-trap and the house-drain is freely open to the passage of air to the sewer, the positive pressure formed just ahead of the discharge down the soil-stack will be slight, generally of the order of one-hundredth of a foot of water or less. Similarly, the negative pressure immediately behind the discharge will be small if the soil-stack is open at the top.

For relatively short lengths of pipe the friction in the flow of air is so slight and its mass so small that the air in the pipe is moved without much compression or expansion of its volume, and thus will readily transmit pressure or relieve it, as the case may be. For lengths of pipe relatively long with respect to the diameter, as may be the case with vent pipes, the resistance to flow may be sufficiently greater and the resulting compression or expansion of the air such that the relief afforded is insufficient for the needs. Since the relief of pressure is the prime purpose of venting traps and plumbing pipes, it is important to know the limits of length and size of vent pipe within which the relief will be sufficient to ensure freedom from loss of seal in the trap, and the determination of such limits was one part of the investigation.

A simple computation will show that only a small change in volume of the air in a pipe, either compression or expansion, will take place before the seal of a trap is broken. Taking normal atmospheric pressure as equivalent to 33 ft. of water, it is seen that a seal of 2 in. corresponds to a pressure of about one two-hundredth of atmospheric pressure. A positive or negative air pressure of 2 in. of water will then change the volume of the confined air only about one two-hundredth of itself.

The tests made bear out the observations given above.

II. The Tests

5. *General Conditions.*—The tests were performed in the stairway tower of the University power house. The stairs, fifty feet in height, connect five floors and furnish four landings on which fixtures and other apparatus were set up. The maximum height used for the fall of water in a soil-stack was 46 ft. The soil-stacks terminated at the top within the building from two to five feet above the highest connection to the soil-stack. The roof of the building was about six feet above the top of the soil-stacks. The arrangement of piping was equivalent to that which might be found in a four- or five-story building.

In making the tests an arrangement of piping was set up by which the desired conditions could be studied. All the factors affecting the test were held as nearly constant as possible, except two. Of these two, one was varied a known amount and the effect on the other was observed. When the relation between the two had been studied sufficiently under these conditions, a single change was made in some other factor, and the two varying factors were again observed.

The following is an example of the procedure: In attempting to determine the proper size of vent pipe to use under different conditions among the factors involved were the size of the soil-stack, the height of fall of water in the soil-stack, the length of the connecting pipe between the trap in which the pressures were observed and the soil-stack, the diameter of the trap, the depth of seal in the trap, the diameter of the vent pipe, the length of the vent pipe, the type of the vent, and the rate of discharge (gallons per minute) into the soil-stack. In the tests all of the conditions were fixed except the rate of discharge into the soil-stack and the pressures observed in the U-tube or trap. Various rates of discharge were tried and the greatest change in the level of the water in the U-tube or trap above and below the normal position was observed. After a number of observations, ranging from five to one hundred or more, had been made under such conditions the length of the vent pipe was changed and another series of observations was made under the new condition. After tests with several lengths of vent pipe were completed, the diameter of the vent pipe was changed, then the height of fall of water in the soil-stack, and so on, until all conditions apparently affecting the test had been investigated.

The recorded readings were then averaged and the tendencies of the minimum, average, and maximum readings were studied in order that conclusions might be reached.

Many preliminary tests were necessary, which involved the calibration and standardization of the apparatus used and the determination of the approximate limits of pressures, sizes of pipe, and other conditions which would be met in the final tests. In the first preliminary tests standard plumbing fixtures were used. These were replaced by calibrated orifice tanks from which the discharge could be controlled so as to equal that from any number of fixtures up to the equivalent of eight to ten water-closets discharging simultaneously. Water containing no solid or suspended matter was used in all the tests except in the series of tests to find the effect on the pressures in traps of mixing solid matter with the discharge from water-closets. As a result of the preliminary tests uniform conditions of discharge, diameter, and type of traps and depths of seal were used in most of the final tests. The conditions are discussed in subsequent sections.

The pressures were affected by many different factors such as the formation of a vortex (whirlpool) in falling down the soil-stack, the breaking into a fine spray at some point in the fall of the water, the adhering of the water to the sides of the pipe in one case and falling down the center of the pipe in another case, etc. The result was that readings of pressure were seldom identical. Conclusions were drawn from a study of a large number of observations made under apparently the same conditions rather than by placing dependence on a fine degree of accuracy of a few observations.

6. *Pressures.*—When water flows in the waste pipes of a plumbing system the air in the pipes is compressed or rarefied and put in motion and thus pressures above or below atmospheric are created. An attempt has been made, in Section 4, to explain why such pressures are created. The pressures resulting from the flow cause the change of level of water in U-tubes connected to the pipes in the plumbing system. The difference of level of the water in the U-tubes is not an accurate measure of the pressure but since the change of the level of the water in the U-tube is of more importance in plumbing design than the actual pressure, and each is dependent on the other, the change or difference of level has been reported as pressure. The change of level was observed through glass windows in iron U-tubes or through glass tubes. The U-tubes were connected to the pipes as shown in Fig. 1 and other figures.

The air pressures were not steady but fluctuated widely as water passed down the soil-stack, and consequently, the water surface in the U-tubes moved rapidly up and down, resulting in some difficulty in reading. The fluctuations in pressure were so rapid at times that the water column in the U-tube was broken, but generally the motion of the water could be followed by the eye.

The observations of pressure were generally made in the leg of the U-tube farthest away from the pipe to which it was connected. Pressures above atmospheric were, therefore, shown by a rise of the water in this leg of the U-tube. The pressure recorded was measured by the greatest change in level of the water, either upwards or downwards. The observations of pressures were made and recorded to the nearest 0.01 ft. (about 1/8 in.) of water. Where the legs of the U-tube were of equal diameter the pressure was recorded as twice the maximum change in level of the water because the total height of water column supported by air pressure in such a U-tube is equal to twice the change in level of the water surface in one leg of the U-tube, as shown in Fig. 1.

7. *U-tubes.*—In the final tests the U-tubes were similar to those shown in Fig. 1. The outlet leg, the two elbows, and the close nipple between them were made of standard threaded pipe and fittings. The inlet leg usually consisted of a glass tube of the same diameter as the outlet leg; in some cases an iron pipe in which a glass window had been placed was used. Each leg was from 30 to 36 in. long and 2 in. in diameter. The depth of water used was 15 in. The U-tubes, which are virtually unvented traps, were connected to the plumbing systems in the same way as standard traps except that no fixture was attached to the inlet leg during any tests but those on self-siphonage.

8. *Rates of Discharge.*—Water was discharged from a specially arranged tank in a manner similar to the discharge from a water-closet. The tank was arranged to permit the discharge of water at rates equal to that of from one to nine or ten water-closets discharging simultaneously. The position of the tank was changed to introduce water into the plumbing system at any desired point. The use of the tank avoided the trouble and expense of a number of fixtures and facilitated the making of tests.

The tank was 2 ft. wide, 6 ft. long, and 2 ft. deep. In the bottom were three circular orifices, 2 in., 3 in., and 4 in., in diameter respectively. In fixing the rate of discharge for any test, the tank was filled with water to a predetermined level which would give the rate desired when the plug was quickly removed from the orifice. No water entered the tank while the plug was not in the orifice. The discharge was allowed to continue for about 7 to 10 seconds, then the plug was inserted in the orifice and the flow ceased. The initial depth of water to be put in the tank was determined by measuring the volume of water which passed the orifice in 10 seconds.

The rate of discharge in a test is expressed as the number of gallons of water which will pass a certain point in one minute. No account was taken of the fact that the rate varies slightly during the emptying of a water-closet, as this variation in rate was assumed to have no effect on the pressures produced. Although none of the tests lasted as long as one minute the rate of discharge was determined by computing the volume of water which would have been used if the test had lasted for one minute. For example, if the test lasted 10 seconds, the rate of discharge would be expressed as six times the number of gallons used in 10 seconds. The rates of discharge used varied between 10 and 450 gallons per minute.

9. *Piping and Equipment.*—All piping was cast-iron pipe, galvanized iron pipe, or steel pipe, clean and new. Standard or extra-heavy soil-pipe with leaded joints was used for the soil-stacks. Leaded, flanged, and threaded joints were used for the horizontal waste pipes and for the vent pipes. The only valves used were gate valves, which gave a clear opening equal to the diameter of the pipe. In cases where it was desired to close off a pipe without the use of a valve, heavy rubber diaphragms were inserted between two flanges. Sanitary tees and ells were used on all waste pipes except where space limitations prevented. Standard water pipe fittings were used on the vent pipes.

10. *The Effect of Diameter of U-tube or Trap on the Observed Pressures.*—These tests were made to determine whether the same diameter of U-tube or trap need be used in all tests. For example, it was desired to know whether a trap two inches in diameter would show more or less movement of the water level than a trap one inch in diameter when both were subjected to the same applications of pressure.

One arrangement of piping used consisted of a 4-in. soil-stack, 50 ft. long, open at the top about two feet above the point where the water entered and connected at the bottom to a 4-in. house-drain about 4 ft. long. U-tubes were connected at four different points along the soil-stack through 4-in. sanitary Y-branch connections. The first tests were made with glass U-tubes ¼ in. in diameter; afterwards these were replaced by glass U-tubes ⅞ in. in diameter. The water entered the

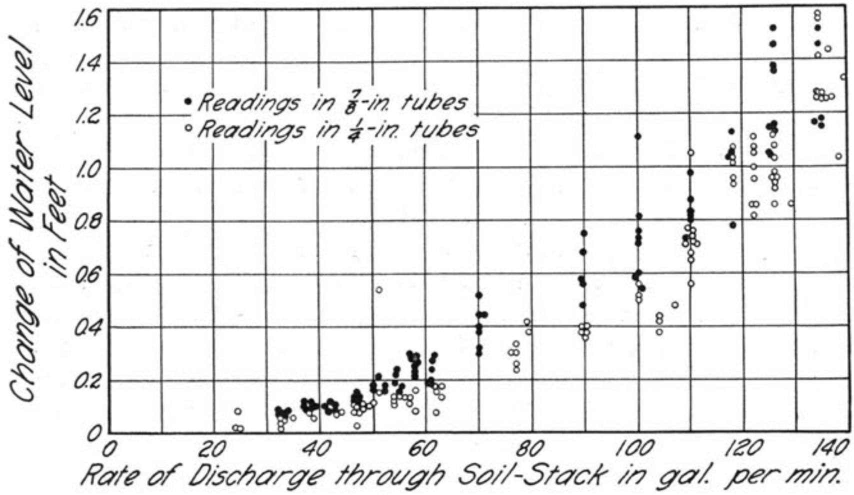


FIG. 3. CHANGE OF WATER LEVEL IN ¼-IN. AND ⅞-IN. U-TUBES FOR VARIOUS RATES OF DISCHARGE

soil-stack through a 4-in. sanitary Y-branch from a 4-in. horizontal waste pipe about 10 ft. long.

The tests were made by discharging water down the soil-stack for from 7 to 10 seconds at a predetermined rate. While the water was falling down the soil-stack readings were taken of the change of the level of the water in the U-tubes.

Some of the readings made in the lowest of the four U-tubes, which was placed about 6 ft. above the bottom of the soil-stack, have been plotted in Fig. 3. It is evident from this figure that the changes of water level with the ⅞-in. U-tube are greater than with the ¼-in. U-tube. The results of these tests indicate that U-tubes of the diameters used will not show the same change of water level under the same applications of pressures.

Similar tests were made with 2-in., 3-in., and 4-in. U-tubes. The apparatus used consisted of a 4-in. soil-stack similar to that used in the preceding test. Water entered the soil-stack at the same height above the house-drain as before. The U-tubes tested were of the type shown in Fig. 1. The vertical portion was 3 ft. long, making possible a depth of water of at least 18 in. The depth used in this series of tests varied between 6 and 18 in., but for any one test all the tubes contained the same depth of water. All three U-tubes were connected to a short hori-

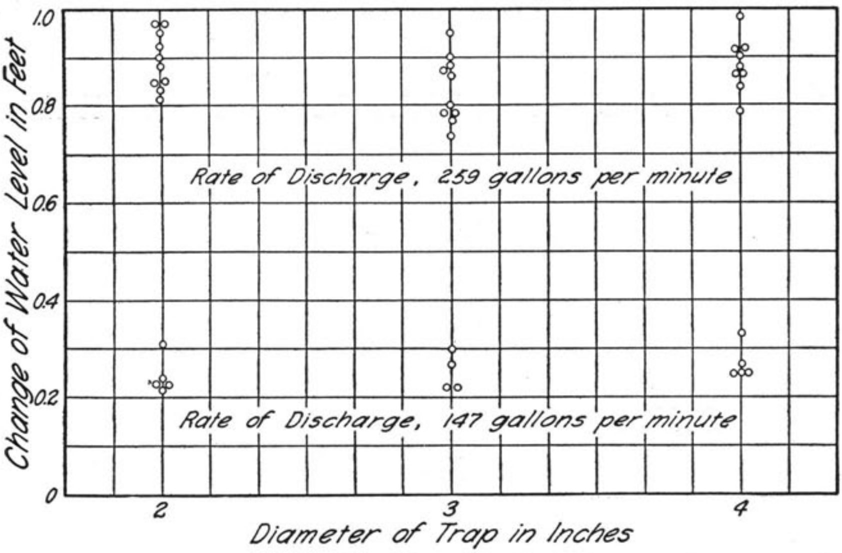


FIG. 4. CHANGE OF WATER LEVEL IN 2-IN., 3-IN., AND 4-IN. U-TUBES FOR TWO RATES OF DISCHARGE

zontal pipe, 3 in. in diameter, which was connected to a 4-in. soil-stack about 26 ft. below the point where the water entered. The U-tubes were not vented. The top of the soil-stack and the end of the house-drain were open to the atmosphere. The total fall of water in the soil-stack was 46 ft.

The tests were conducted in a manner similar to those made on the apparatus first described. Typical readings of the change of the level of the water in the 2-in., 3-in., and 4-in. U-tubes have been plotted in Fig. 4. Each point shown represents the greatest change of the water level in a trap for a single test. Although the readings were taken under the same conditions of rate of discharge (gallons per minute) into the soil-stack, the changes in water level observed in two different tests were seldom identical, this resulting probably from the variable manner in which the falling water may behave. (See last paragraph, Section 5.) The dispersion of the points in Figs. 3 and 4 illustrates the necessity of making a number of repetitions of a test and of studying the tendencies of all the readings, and the futility of attempting to draw conclusions from any one test. The dispersion of the points in Fig. 4 is less than that shown in Fig. 3, and no greater dispersion is shown in the 4-in. trap than in the 2-in. trap.

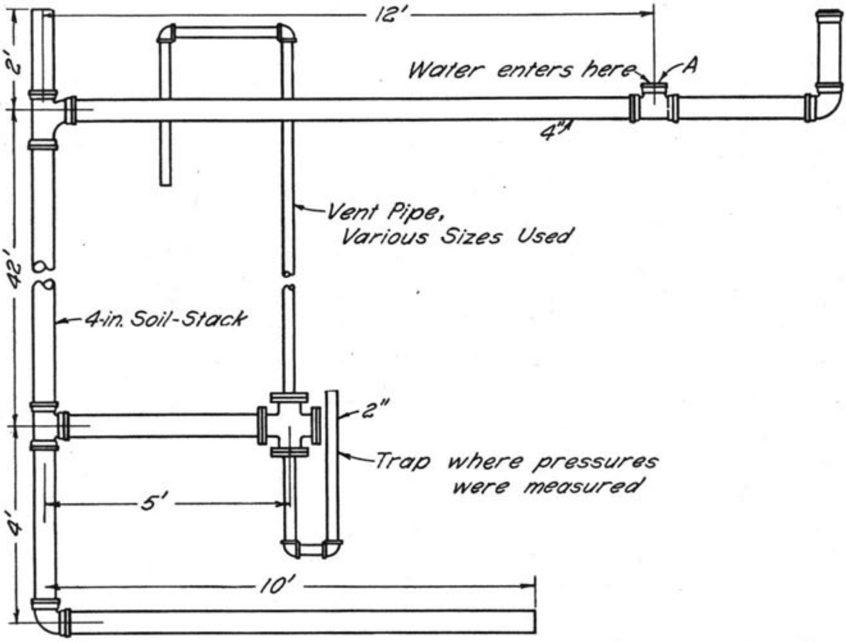


FIG. 5. APPARATUS USED FOR DETERMINING THE PRESSURES CREATED IN A PLUMBING SYSTEM BY WATER FALLING DOWN THE SOIL-STACK

It is concluded, as a result of these tests, that the maximum change of level of the water in a U-tube or trap resulting from the applications of pressure is approximately the same for all diameters of U-tubes or traps provided the tube is sufficiently large to render negligible the effect of friction in retarding the movement of the water. The minimum diameter of trap to satisfy this condition seems to be about one inch.

11. *The Effect of the Depth of Water in a U-tube or Trap on the Observed Pressures.*—These tests were made to learn whether a uniform depth of water in the U-tubes or traps need be adopted for use in other tests. For example, it was desired to learn whether three inches of water in a trap would move more or less than three or four times that amount of water in the same trap when subjected to the same applications of pressure. The depths of water used in the tests varied between 4 in. and 30 in.

The apparatus used consisted of a 2-in. U-tube or trap connected to a 4-in. soil-stack as shown in Fig. 5. The vent shown in the figure was

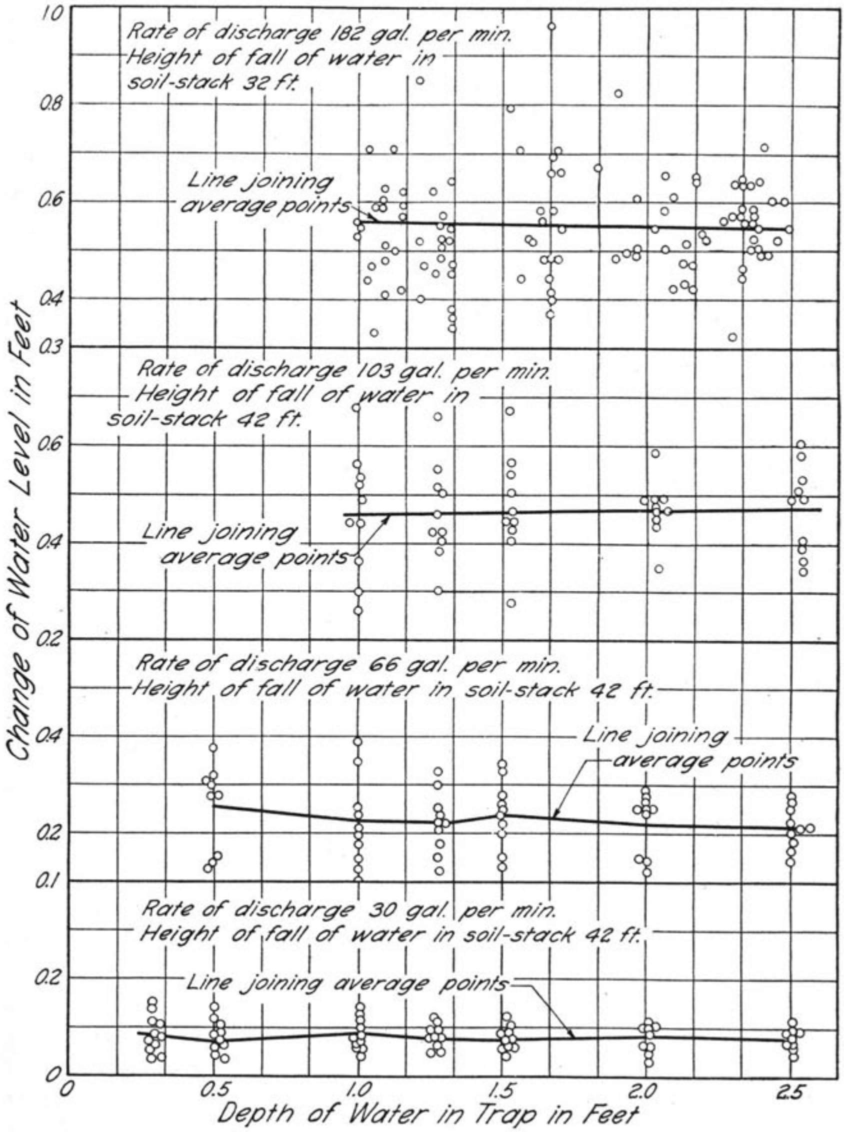


FIG. 6. CHANGE OF WATER LEVEL IN 2-IN. U-TUBES CONTAINING DIFFERENT DEPTHS OF WATER FOR VARIOUS RATES OF DISCHARGE AND TWO HEIGHTS OF FALL IN THE SOIL-STACK

closed at the crown of the trap. Water entered the top of the soil-stack at rates between 30 and 182 gallons per minute for 7 to 10 seconds. The maximum change of the water level in the U-tube or trap was observed.

Typical observations are plotted in Fig. 6. The principal factor affecting the amount of the change of level of water in the trap, for any particular height of fall in the soil-stack, is the rate of discharge down the soil-stack. For a rate of 30 gallons per minute for 7 to 10 seconds, falling about 42 ft. in the soil-stack, the average change for all the tests made was about .08 ft., or 1 in. The maximum change with this rate of discharge was about 0.17 ft., or 2 in. The average change when the rate of discharge was 182 gallons per minute for 7 to 10 seconds falling about 32 ft. in the soil-stack was closely 0.55 ft., or 6½ in. The maximum change under these conditions was 0.94 ft., or 11¼ in.

The distribution of the points in Fig. 6 shows that there is a slight variation in the change of level of the water in the U-tube or trap with different depths of water in the trap, under the same rates of discharge down the soil-stack. The change of level is greater for the smaller depths of water used, due probably to the smaller mass of water and the smaller length of water column to be moved.

It is concluded that the effect of different depths of water in the U-tubes or traps can be considered negligible because the difference between the average changes of level of the water for large and for small depths of water therein is small. It is also concluded that the withdrawal of water from a trap will not weaken its resistance to the passage of air through it, provided the volume of water remaining in the trap is sufficient to fill the connection between the two legs of the trap and to form a vertical column of a height equal to the depth of seal in that leg of the trap in which the water rises. It follows that the losses of water from traps, caused by ordinary small changes in pressure in a well-designed plumbing system, do not weaken the seal of the trap.

It will be noted in Fig. 6 that the maximum pressure observed is in no case as great as twice the average pressure. If it be assumed that the maximum pressure which may be exerted on a trap may be double the average pressure, a trap with a seal equal to double the average pressure read with any depth of seal should be able to resist any pressures resulting from conditions similar to these tests.

12. *The Relative Strength of Deep-Seal and Shallow-Seal Traps to Resist Breaking of the Seal.*—It follows from the conclusions drawn in

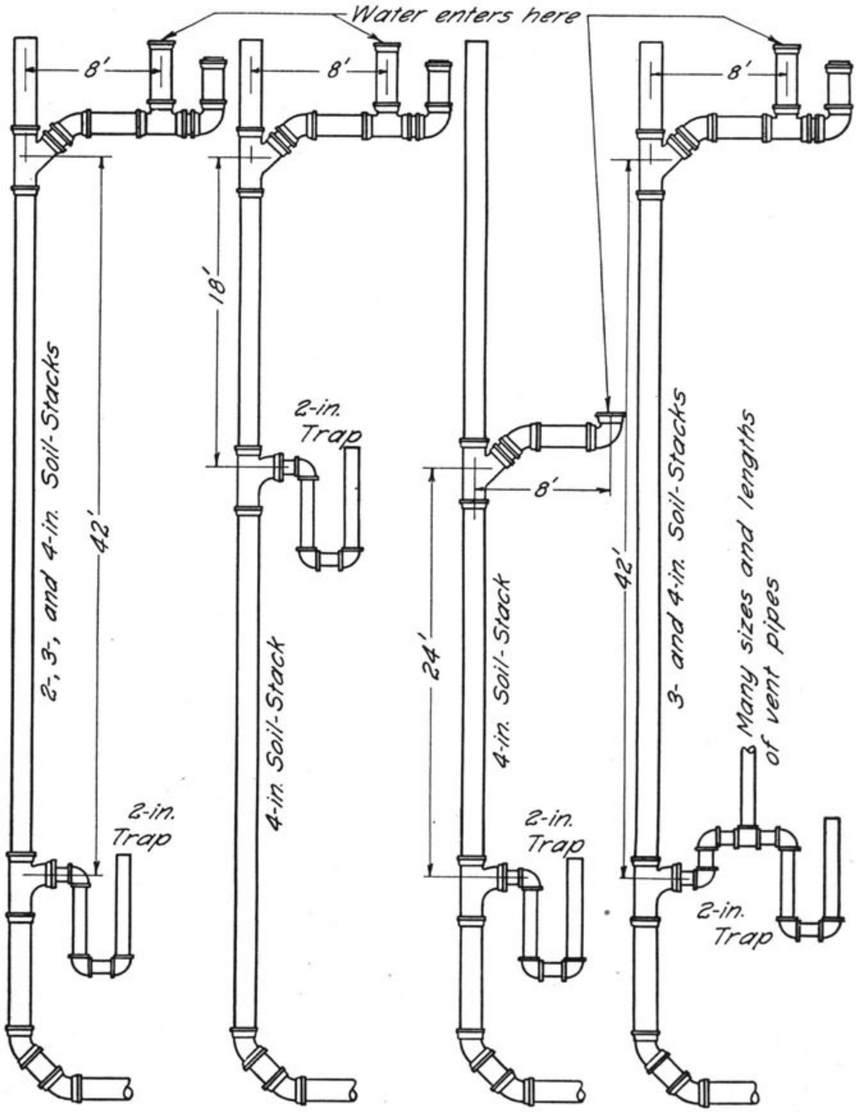


FIG. 7. APPARATUS USED FOR DETERMINING THE PRESSURES CREATED IN A PLUMBING SYSTEM BY A DISCHARGE DOWN THE SOIL-STACK

TABLE 1

RATE OF DISCHARGE FROM WATER-CLOSETS

Time of Discharge seconds	Quantity Discharged gallons	Average Rate gallons per minute	Time of Discharge seconds	Quantity Discharged gallons	Average Rate gallons per minute
13	4.63	21.2	6	3.98	39.8
10	4.25	25.5	6	4.00	48.0
7	4.25	35.4	7	4.10	41.0
6	4.22	42.2	7	3.70	37.0
6	4.02	40.2	6	3.50	42.0
9	4.80	32.0	5	3.7	44.4
7	4.35	37.3	7	4.1	35.0
Average for 14 water-closets......................			7.3	4.1	33.7

Section 11 that the strength of the trap to resist the passage of air through it is independent of the depth of water in the trap if there is sufficient water in it to fill the connection between the two legs and to form a vertical column of a height equal to the depth of seal in that leg in which the water rises.

It may then be concluded that the resistance of a trap to the passage of air through it (breaking of the seal) varies directly with the depth of the seal.

13. *The Rate of Discharge from Water-Closets.*—Water was discharged into the plumbing systems tested in this investigation at predetermined rates through orifices in a tank, as is described in Section 8. The use of the tank avoided the difficulties attendant on the use of a number of water-closets. To discharge the water from the tank in the same manner and at the same rate as one or more water-closets it was necessary to study the rate and manner of discharge of water-closets. The apparatus used in the study consisted of a ten-gallon tank suspended on a spring balance. The water-closet to be tested discharged into this tank. The rate at which the water entered the tank was determined from a line drawn on a record sheet, moving at a constant speed, by a pencil attached to the spring balance.

The results of tests of fourteen types of water-closets are given in Table 1. Six of the water-closets tested were equipped with high-up tanks and eight with low-down tanks. These fixtures were taken from the regular stock used at the University and are fairly representative of the different types in common use. The rates of discharge from the automatic flushing valve type of water-closets were not measured. The average rate of discharge for the fourteen water-closets was approximately 34 gallons per minute for a period of 7 seconds, and the average total discharge about 4 gallons. The maximum rate of discharge observed was 44.4 gallons per minute, for a period of 5 seconds. A rate of discharge of 50 gallons per minute for 7 seconds has then been assumed for the purpose of converting rates of discharge used in the tests into an equivalent number of water-closets, and for making recommendations concerning the design of plumbing. The rate of 50 gallons per minute, although greater than any of the rates found in the tests, was assumed as being on the side of safety in plumbing design.

The rates of discharge from other fixtures were not measured, as it is assumed that water-closet discharges cause the greatest pressures in plumbing systems.

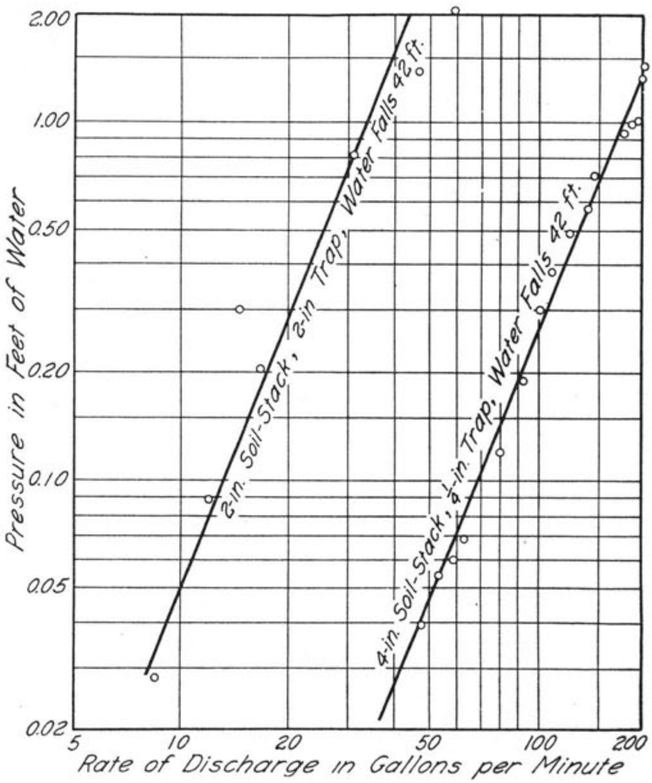


FIG. 8. PRESSURES IN A PLUMBING SYSTEM AND THE RATE OF DISCHARGE DOWN THE SOIL-STACK

The traps in which the pressures were measured were not vented.

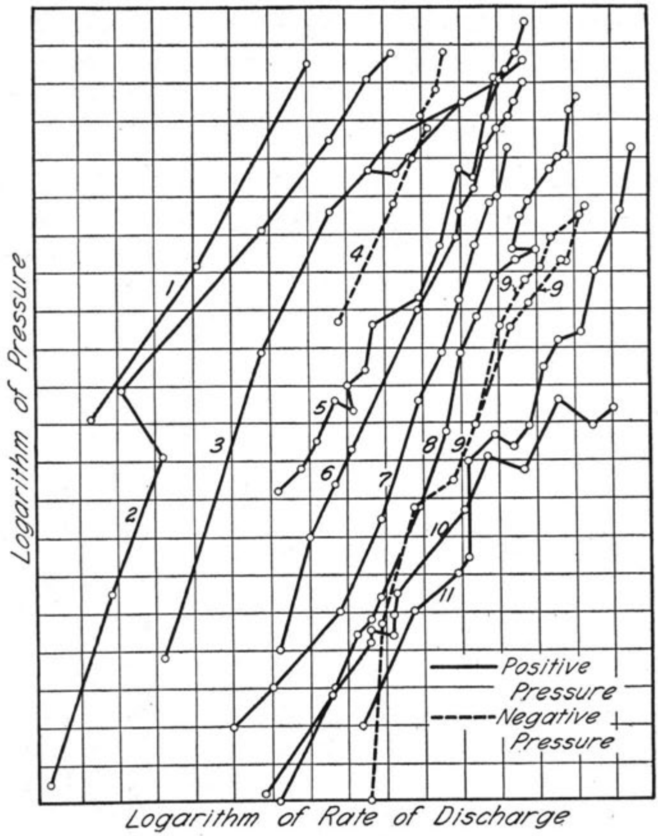


FIG. 9. PRESSURES IN A PLUMBING SYSTEM AND THE RATE OF DISCHARGE DOWN THE SOIL-STACK

The traps in which the pressures were measured were not vented. The line numbers are explained in Table 2. The lines were placed to show slope only. Absolute values of the pressures and discharge are not shown and the scale is not the same for the different lines.

14. *The Relation Between the Rate of Discharge Down a Soil-Stack and the Resulting Pressures in a Plumbing System.*—The discharge of a fixture into a soil-stack will cause the water to oscillate in the trap of a fixture that is connected to the soil-stack at a lower level. When two or more fixtures are discharged simultaneously at the higher level the oscillation of the water in the lower trap will increase. By determining the relation between the amplitude of oscillation of the water in the

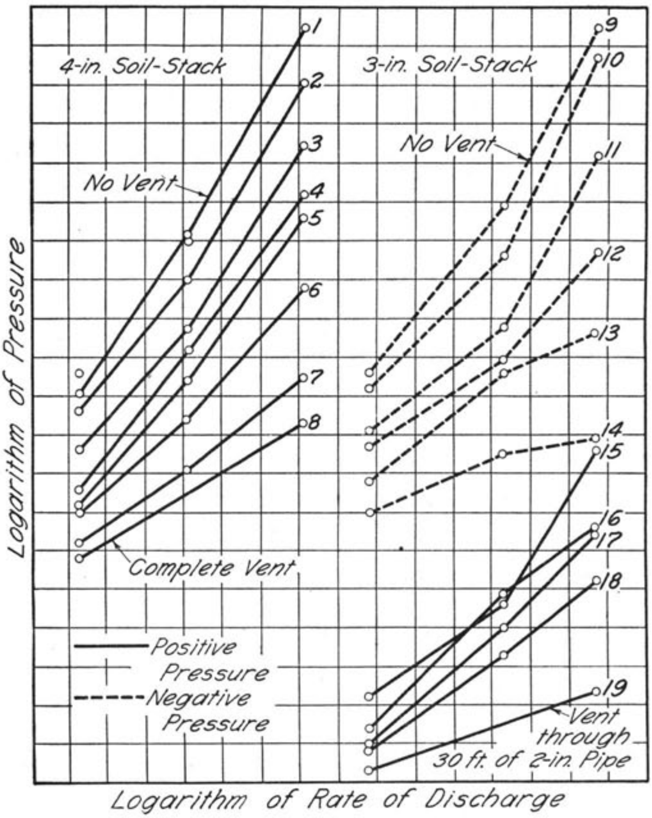


FIG. 10. PRESSURES IN A PLUMBING SYSTEM AND THE RATE OF DISCHARGE DOWN THE SOIL-STACK

The traps in which the pressures were measured were vented. The line numbers are explained in Table 3. The lines are placed to show slope only. Absolute values of pressure and discharge are not shown and the scale is not the same for the different lines.

trap at the lower level and the number of fixtures that discharge simultaneously, information of value in the subsequent research work and in the design of plumbing has been obtained.

A diagram of the apparatus used in the tests is shown in Figs. 5, 7, and 18. It is to be noted in these figures that the lengths of the horizontal waste pipes between the traps and the soil-stack are not the same. Other tests reported in this bulletin have shown that pressures in traps at different distances, up to 25 ft., from the soil-stack are

TABLE 2

EXPLANATION OF LINE NUMBERS IN FIG. 9

The Apparatus is shown in Fig. 7.

Line Number	Diameter of Soil-Stack inches	Height of Fall of Water above Point where Pressure was Measured feet	Height of Fall of Water below Point where Pressure was Measured feet	Diameter of U-tube Used for Measuring Pressures inches	Character of Pressure Reported
1	4	42	4	2	+
2	2	42	4	2	+
3	3	42	4	2	+
4	4	18	28	7/8	−
5	4	42	4	7/8	+
6	4	42	4	7/8	+
7	4	42	4	7/8	+
8	4	42	4	1/4	+
9	4	22	24	1/4	−
10	4	42	4	3	+
11	4	22	24	1/4	+

TABLE 3

EXPLANATION OF LINE NUMBERS IN FIG. 10

The height of fall of water above the point where pressure was measured was 42 ft. and below this point was 4 ft. The diameter of the U-tube used for measuring pressures was 2 in.

The Apparatus is shown in Fig. 7.

Line Number	Diameter of Soil-Stack inches	Character of Pressure Reported	Diameter of Crown Vent inches	Length of of Crown Vent feet
1	4	+	0	0
2	4	+	3/4	101
3	4	+	3/4	51
4	4	+	3/4	11
5	4	+	1	50
6	4	+	1	11
7	4	+	1½	6
8	4	+	1½	0
9	3	−	0	0
10	3	−	3/4	50
11	3	−	1	50
12	3	−	1½	50
13	3	−	2	50
14	3	−	2	20
15	3	+	0	0
16	3	+	3/4	50
17	3	+	1	50
18	3	+	1½	50
19	3	+	2	50

the same for the same amount of water falling into the soil-stack. Hence the differences in the length of the horizontal waste pipes have not been considered as affecting the pressures observed in these tests. Water was discharged down 2-in., 3-in., or 4-in. soil-stacks at various rates for approximately 7 seconds. Readings were taken of the change of water level in traps placed at different points on the soil-stack. The conditions of venting of the traps were varied.

The results of typical tests are shown in Figs. 8, 9, and 10 in the form of curves in which the variables are the logarithm of the rate of discharge down the soil-stack and the logarithm of the pressures read in the traps. The line numbers of Figs. 9 and 10 are explained in Tables 2 and 3.

It is concluded, from a study of many such diagrams, that for *unvented* traps the relation between the rate of discharge Q down the soil-stack and the pressures P (either positive or negative) created in the soil-stack can be expressed as $P = KQ^{5/2}$ in which K is a coefficient dependent on the piping arrangement, the units in which Q and P are expressed and other conditions of the test such as the diameter of the soil-stack, the connection between the soil-stack and horizontal waste pipe, etc. It is seen from this equation that the pressure varies as the five-halves power of the rate of discharge.

The value of K was found to vary between .00016 for discharges falling 42 ft. down a 2-in. soil-stack, and .00003 for discharges falling the same distance down a 4-in. soil-stack. In computing these values of the coefficient K the rate of discharge was expressed in gallons per minute and the pressures in feet of water. The highest pressure it was possible to read with the length of U-tube used was that corresponding to a water column of about 3.0 ft. Greater pressures blew the water out of the trap. This maximum pressure of 3.0 ft. was created by rates of discharge of about 260 gallons per minute or more (for 7 seconds) falling 42 ft. in a 4-in. soil-stack. A rate of discharge of about 80 gallons per minute (for 7 seconds) falling 42 ft. in a 2-in. soil-stack created about the same pressure.

For *vented* traps, the tests for which were made on the apparatus shown in Figs. 5 and 18, representative values have been plotted in Fig. 10 by the use of the logarithm of the rate of discharge Q and the logarithm of the pressure P. In each case only three different values of Q were observed, but it is evident from the lines that their slope is a variable dependent on the amount of venting. The relation between Q and P for vented traps has, therefore, been expressed as $P = KQ^m$ in which K is a coefficient the value of which depends on the size and arrangement of the discharge pipes and the height of fall of water, and m is an exponent the value of which depends on the character of the venting. The values of K are similar to those for unvented traps. The values of m vary from about one-third when the crown of the trap is fully opened to five-halves for no vent. For example, if it has been found by test that the discharge of a water-closet causes the water in the trap of some other fixture to move 1 in., the discharge of two water-closets simultaneously will cause it to move $2^{5/2}$ times 1 in. or 5⅝ in. if the trap is not vented. If the trap is well vented the discharge of two water-closets simultaneously may cause the water to move only $2^{1/3}$ times 1 in. or 1¼ in.

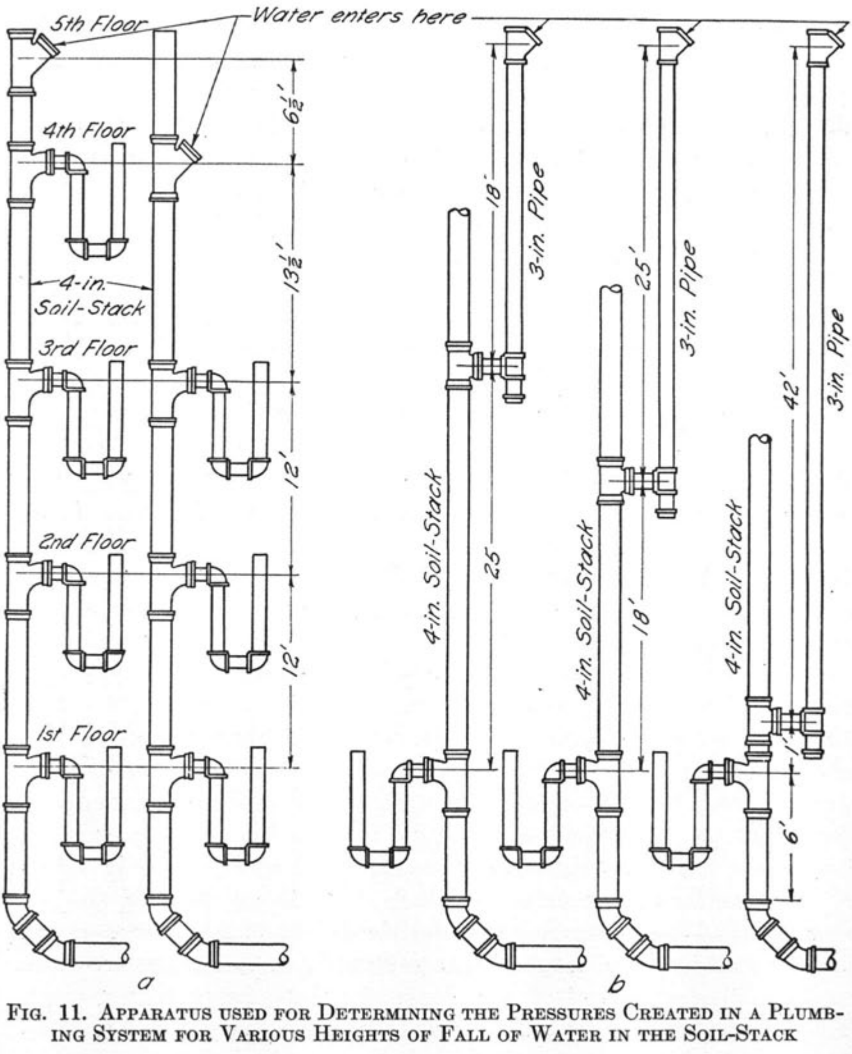


FIG. 11. APPARATUS USED FOR DETERMINING THE PRESSURES CREATED IN A PLUMBING SYSTEM FOR VARIOUS HEIGHTS OF FALL OF WATER IN THE SOIL-STACK

No tests were made to determine the relation between the rate of discharge into a horizontal waste pipe and the pressures created in the traps of fixtures connected to the same waste pipe.

15. *The Relation Between the Height of Fall in the Soil-Stack and the Resulting Pressures in a Plumbing System.*—The discharge of a fixture into a soil-stack will produce pressure and cause the water to oscillate in the trap of a fixture that is connected to the soil-stack at a lower level. When a similar fixture at a still higher level is discharged into the same soil-stack the oscillation of the water in the trap of the lower fixture is greater.

By determining the relation between the pressure in the trap at the lower level and the height of fall of water in the soil-stack, information of value in the subsequent research and in the design of plumbing has been obtained.

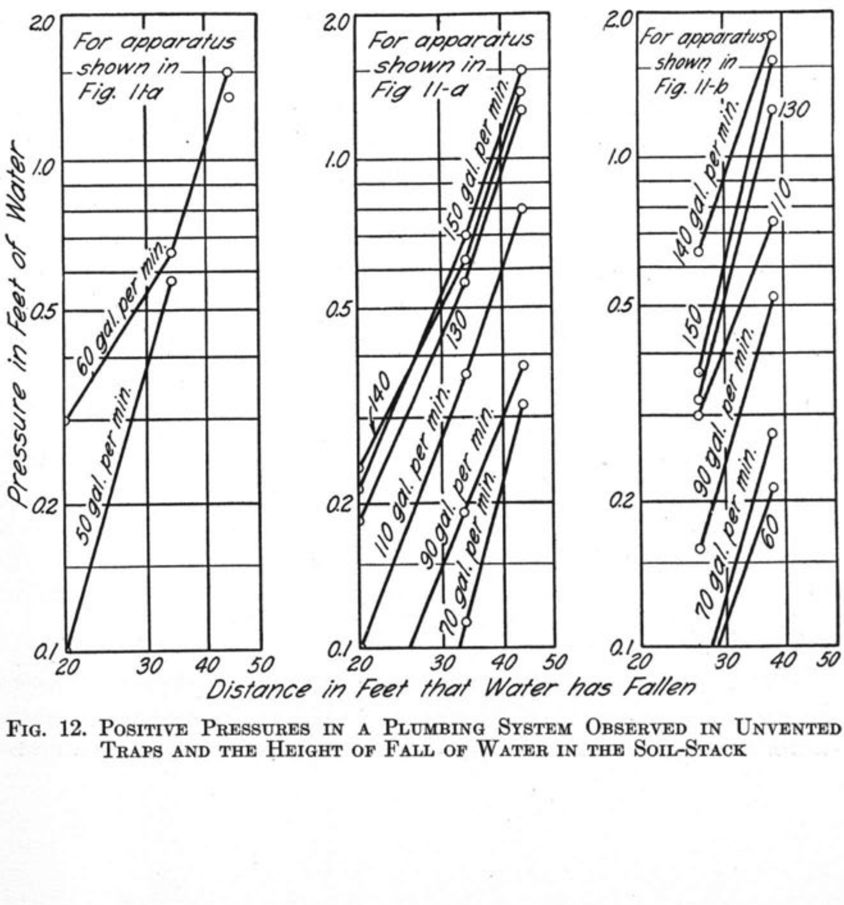


FIG. 12. POSITIVE PRESSURES IN A PLUMBING SYSTEM OBSERVED IN UNVENTED TRAPS AND THE HEIGHT OF FALL OF WATER IN THE SOIL-STACK

A diagram of the apparatus used in the tests is shown in Fig. 11. Water entered the soil-stacks at different levels and readings were taken of the maximum change of the water level in traps at different points on the soil-stacks.

The results of typical tests are shown in Fig. 12 in the form of logarithmic curves in which the variables are the height of fall of water down the soil-stack in feet and the pressures read in the traps, expressed in feet. It is concluded, from a study of Fig. 12, that the positive pressure created in unvented traps in a plumbing system caused by water falling at a given rate for about 7 seconds down a soil-stack, varies as the five-halves power of the height of fall of water in the soil-stack.

The relation between the positive pressures created in *vented* traps and the height of fall of water in the soil-stack was not tested. It is probable that the relation would be the same for different amounts and methods of venting, because it was found in tests on vented traps that the effect of venting on pressures of different magnitude was about the same; that is, if a 2-in. pressure in an unvented trap were reduced 50 per cent by venting the trap, a 5-in. pressure in the same unvented trap would also be reduced 50 per cent by the same vent.

It is also concluded from other tests that negative pressure will be produced only at points below the point of entrance of water to the soil-stack. The tests showed that negative pressure is dependent both on the vertical distance the water falls to the point where the negative pressure is measured and on the vertical fall below this point. It has been assumed that the relation between negative pressure and the height of fall of water in a soil-stack is the same as the relation between positive pressure and the height of fall of water in the soil-stack.

The conclusion concerning the relation between positive pressures created in a plumbing system by water falling down a soil-stack and the height of fall of water in the soil-stack indicates that if the discharge from a fixture on the first floor falls 10 ft. to the basement and causes the water in a trap in the basement to move 1 in. the discharge from a similar fixture on the second floor falling 20 ft. to the basement will cause the water in a trap in the basement to move $2^{5/2}$ times 1 in. or $5\frac{5}{8}$ in., provided the venting of the two traps is the same.

16. *The Useful Capacity of 2-in., 3-in., and 4-in. Soil-Stacks.*—The capacity of a pipe is generally understood to be the rate at which water will flow uniformly and steadily through the pipe for a given hydraulic

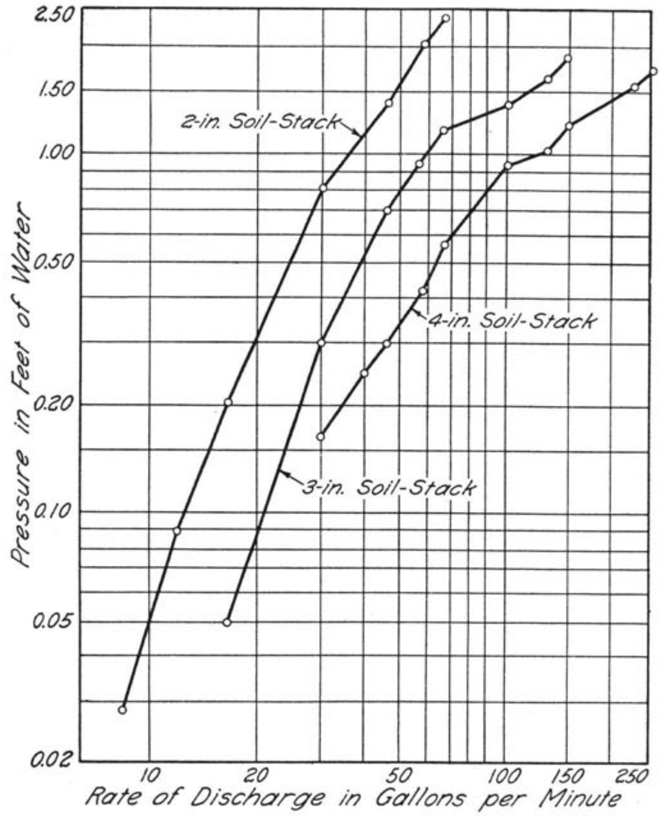


FIG. 13. PRESSURES IN A PLUMBING SYSTEM AND THE RATE OF DISCHARGE DOWN THE SOIL-STACK

These are the same as lines 2, 3, and 10 in Fig. 9 with absolute values of pressures and discharge shown.

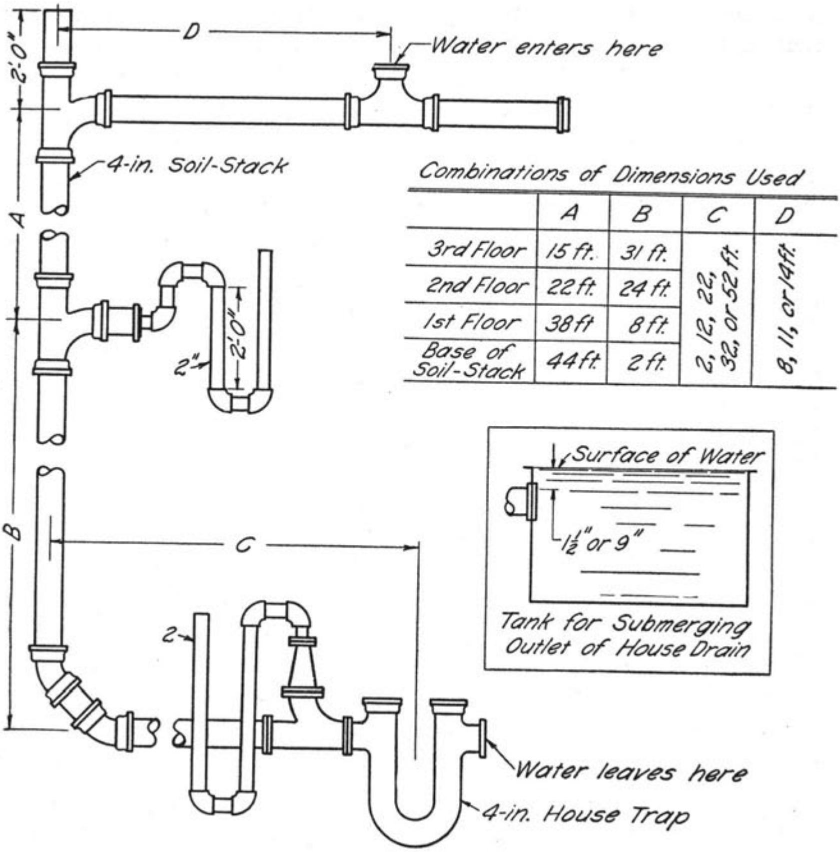
slope. The capacity of a soil-stack to receive the discharge from plumbing fixtures cannot be so expressed because the flow of air and water down the soil-stack is neither uniform nor steady. A vertical pipe will allow more water to fall through it freely than can enter it freely from one horizontal pipe.

The determination of the rate at which water would enter a soil-stack freely from one horizontal waste pipe was made from lines 2, 3, and 10 in Fig. 9. It will be noted that the upper portions of these lines curve to the right, which indicates that the pressure P is not increasing as the five-halves power of Q for values of Q greater than that corresponding to the point where the plotted line ceases to be straight. It is assumed that this was due to the restriction of flow at the entrance to the soil-stack, and that the full effect of larger rates of discharge cannot be exerted to increase the pressures in the plumbing system. Therefore, the point where the line giving the relation between the rate of discharge down a soil-stack and the pressures created in the soil-stack deviates from a straight line will indicate the rate of discharge above which water does not enter the soil-stack freely from one horizontal waste pipe.

Lines 2, 3, and 10 in Fig. 9 have been replotted in Fig. 13. The rate at which water will enter the soil-stack freely from one horizontal waste pipe has been read from these three lines as follows: 2-in. soil-stack, 25 gal. per min. for 7 seconds; 3-in. soil-stack, 50 gal. per min. for 7 seconds; 4-in. soil-stack, 100 gal. per min. for 7 seconds. If water continued to flow at these rates for a period appreciably longer than 7 to 10 seconds it is probable that the pressures in the plumbing system would be different.

In these tests the water entered the soil-stack through a sanitary T of the same size as the soil-stack. The rates of discharge, therefore, represent the approximate rate at which water will enter a soil-stack freely through a sanitary T of the same diameter as the soil-stack. These rates are not the greatest rates at which water can enter or can flow down a soil-stack. The maximum rate at which water will enter a soil-stack freely from one horizontal waste pipe is fixed by the type of the connection admitting water to the soil-stack and by the velocity of approach. In these tests the connection used was a sanitary T; it is highly probable that the recorded capacities would be greater if a sanitary Y had been used.

Water can be made to enter a soil-stack at a higher rate by allowing the pressure to increase in tributary horizontal waste pipes, by using more than one waste pipe at the same or different levels, by using special types of fittings to connect horizontal waste pipes with the soil-stack, and in other ways. Tests have not been made to determine the maximum rate at which water will flow down vertical pipes without creating pressures uncontrollable by venting in plumbing systems, but the indications are that this maximum rate is high and that a 4-in. soil-stack will take all the water that would be delivered to it in a five-story building; that a 3-in. soil stack would take all of the water that would be delivered to it in a three-story residence; and that a 2-in. pipe is unsuitable for use as a soil-stack.



	A	B	C	D
3rd Floor	15 ft.	31 ft.	2, 12, 22, 32, or 52 ft.	8, 11, or 14 ft.
2nd Floor	22 ft.	24 ft.		
1st Floor	38 ft.	8 ft.		
Base of Soil-Stack	44 ft.	2 ft.		

FIG. 14. APPARATUS USED TO DETERMINE THE PRESSURES CREATED IN A PLUMBING SYSTEM AS THE RESULT OF THE USE OF A HOUSE-TRAP, SUBMERGING THE END OF THE HOUSE-DRAIN, OR CHANGING THE LENGTH OF THE HOUSE-DRAIN

The measurements at the base of the soil-stack were made 2 ft. above the house-drain.

17. *The Effect of the Use of a House-Trap on the Pressures in a Plumbing System.*—A diagram of the apparatus is shown in Fig. 14. The house-trap was placed at the end of the house-drain farthest from the base of the soil-stack. This distance is marked *C* in Fig. 14. Water entered the soil-stack 46 ft. above the house-trap at various predetermined rates. Observations were made of pressures in unvented traps at different levels along the soil-stack, at different points in traps connected to horizontal waste pipes of the plumbing system, and in traps

connected to the house-drain at different points. Tests were made with and without a house-trap and also with and without vent to the house-trap. Both openings in the top of the house-trap were left open for tests on a vented house-trap, and both were closed for tests on an unvented house-trap. Both the positive and the negative pressures were read and recorded.

In unvented traps at the two higher levels the first movement of the water indicated a very slight positive pressure. As the water in the soil-stack passed the trap the pressure changed very quickly to negative. The water level in the trap moved up and down violently, the first few movements not being the greatest. When positive pressure appeared again after the first rush of water had passed, it came usually after the maximum negative pressure had been observed. The pressure changed from negative to positive and back to negative again a number of times before the maximum positive pressure was noted. The oscillations of the water were sometimes so rapid as to be difficult for the eye to follow and the column of water in the trap was sometimes broken. After the maximum positive pressure had been reached the oscillation of the water column would slowly cease, sometimes in swings seemingly harmonic, and sometimes in swings disturbed by recurrent puffs of positive or negative pressure or both. In some cases it was not possible to distinguish between the change of the level of the water in the trap caused by the swing of the water after the pressures had ceased and the change of level caused by recurrent puffs of pressure. The first movement of the water in the trap at the lowest level indicated a very slight negative pressure which quickly changed to a relatively high positive pressure. The movements of the water in the lower trap were thereafter similar to the movements described in the traps at the higher levels.

The pressures read in the various traps under different conditions are shown graphically in Fig. 15. The rate of discharge for these tests was 118 gallons per minute for about 7 seconds. It will be seen that these pressures vary between zero when no house-trap is used and approximately $2\frac{3}{4}$ ft. when an unvented house-trap is used. The pressures recorded in this figure represent the average of at least five observations under the same conditions. In a study of this figure it is interesting to note that the use of an unvented house-trap results in a marked increase of both positive and negative pressures in unvented traps everywhere in the plumbing system.

FIG. 15. PRESSURES IN A PLUMBING SYSTEM WITH A HOUSE-TRAP EITHER VENTED OR UNVENTED AND WITHOUT A HOUSE-TRAP

The rate of discharge was 118 gallons per minute.

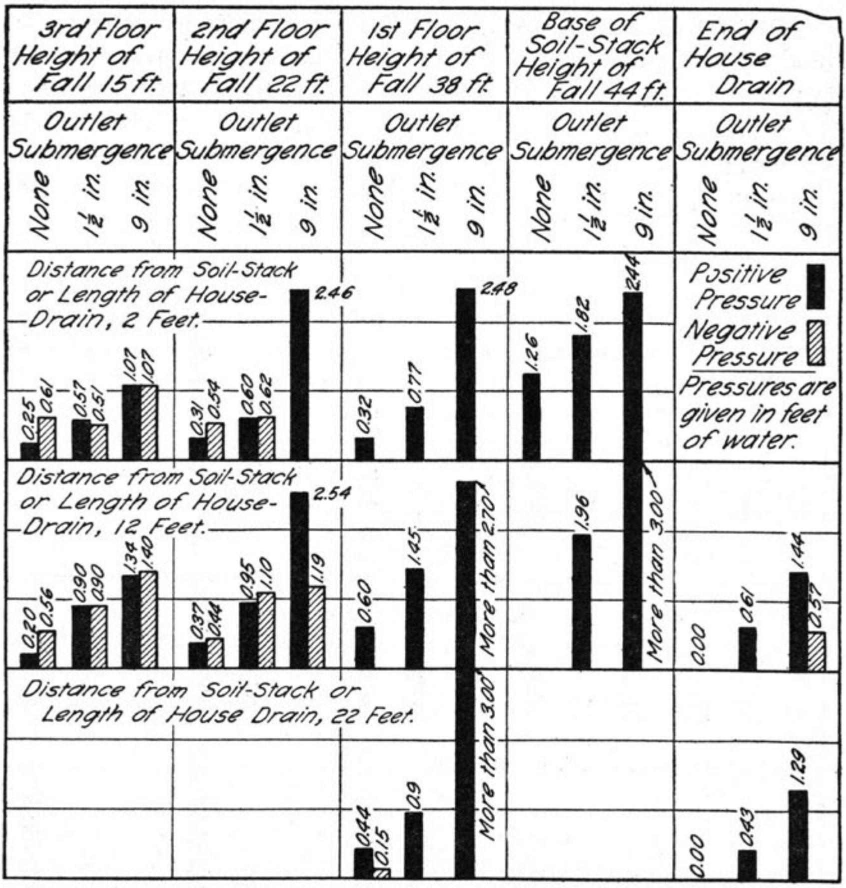


FIG. 16. PRESSURES IN A PLUMBING SYSTEM WITH AND WITHOUT THE END OF THE HOUSE-DRAIN SUBMERGED

No house-trap was used in these tests. The rate of discharge was 118 gallons per minute.

The use of a well vented house-trap, under the conditions of these tests, shows only a slight increase in either positive or negative pressure in the plumbing system over the pressures created when no house-trap is used.

It is therefore concluded that the use of a well vented house-trap does not increase the pressures in a plumbing system, but that the use of an unvented house-trap will result in relatively high pressures. It will be seen further on, in tests to determine the effect of the length of the house-drain, that the use of a house-trap either vented or unvented is undesirable.

18. *The Effect of Submerging the Outlet End of the House-Drain on the Pressures in a Plumbing System.*—It sometimes happens that the sewer into which a house-drain discharges becomes so filled as to submerge the outlet from the house-drain. If no vent is provided in the house-drain the pressures in the plumbing system will be increased. Tests were made to determine the amount of the increase in pressure resulting from such a condition.

The apparatus used in these tests differed from that used in the preceding tests only in that the house-trap was replaced by a tank into which the house-drain discharged beneath the surface of the water in the tank. The arrangement at the end of the house-drain is shown in Fig. 14. The rate of discharge was 118 gallons per minute for about 7 seconds. The distance from the surface of the water in the tank to the top of the inside of the house-drain was 1½ in. for one series of tests and 9 in. for another series. Pressures, both positive and negative, were read in the unvented traps located as described in Section 17.

The pressures read in the various unvented traps under different conditions are given graphically in Fig. 16 and represent an average of at least five observations under the same conditions.

From a study of the figure it is concluded that a slight submergence of the outlet of the house-drain or house-sewer will result in a marked increase of both positive and negative pressures in unvented traps in the plumbing system and that a greater submergence will result in a further increase in pressure. If roof-water leaders are connected to the house-drain and the flow is sufficient to overcharge this drain, the conditions may be expected to be the same as with a submerged outlet. It is concluded that the submergence of the outlet from a house plumbing system should be avoided, but where unavoidable, the venting of the house-drain or the house-sewer at a point above the highest level of water backing up in the house-drain or the house-sewer will give relief.

19. *The Effect of the Length of the House-Drain and House-Sewer on the Pressures in a Plumbing System.*—The house-drain is defined in Section 3 as a waste pipe into which the soil-stacks discharge. It connects with the house-sewer or the street sewer outside of the walls of the building. The house-sewer is defined as the pipe which begins outside of the wall of the building and connects the house-drain with the public sewer in the street. Where the house-sewer is so much larger than the house-drain that the conditions at the junction of the two pipes are equiv-

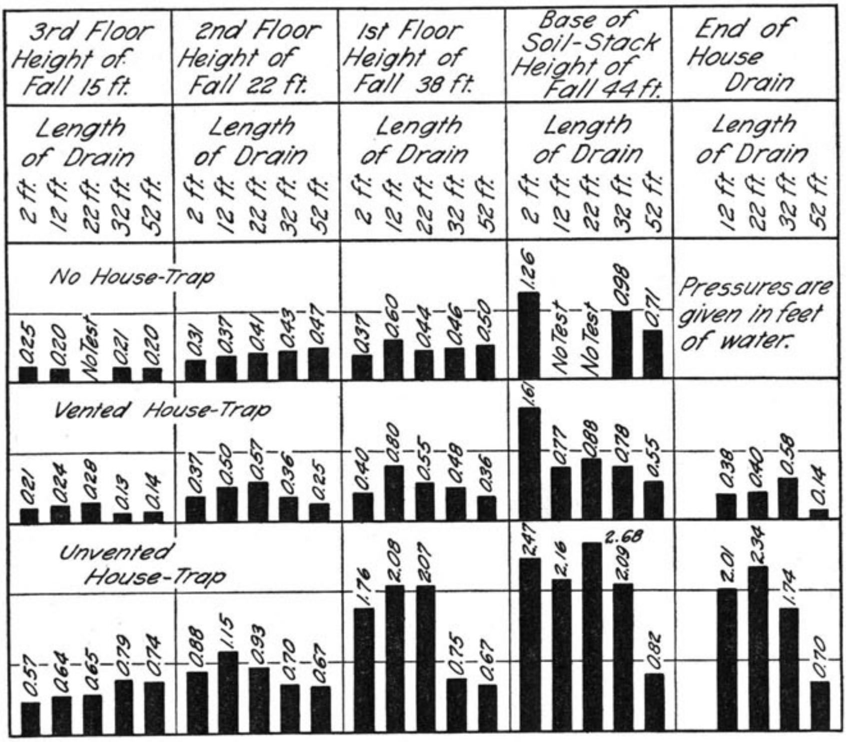


FIG. 17. POSITIVE PRESSURES IN A PLUMBING SYSTEM FOUND WITH DIFFERENT LENGTHS OF HOUSE-DRAIN EITHER WITH OR WITHOUT A HOUSE-TRAP AT THE END

The rate of discharge was 118 gallons per minute.

alent to the discharge of the house-drain into the atmosphere the pressures in the plumbing system will not be affected by the length of the house-sewer. In these tests no house-sewer was used; the house-drain was 4 in. in diameter and it was laid on a slope of about $\frac{1}{4}$ in. to the foot. In some tests it discharged freely into the atmosphere and in other tests a house-trap was connected to the end of the house-drain. The apparatus used in these tests is shown in Fig. 14. The maximum length of house-drain used was 52 ft., and the rate of discharge was 118 gallons per minute for about 7 seconds. The readings of pressure under different conditions are given in Fig. 17.

The results of the tests indicate that the length of the house-drain has some effect on the pressures in a plumbing system, and that this effect is not the same at all points in the plumbing system. The use of a house-trap is shown to result in a marked increase in pressure at certain points. No definite conclusions can be drawn without further tests, but in general it seems from a study of Fig. 17 and similar data that the effect of the length of the house-drain on the pressures in a plumbing system need not be considered and that the use of a house-trap is undesirable.

20. *The Effect of the Closure of the Upper End of the Soil-Stack on the Pressures in a Plumbing System.*—Frost in the portion of a soil-stack protruding above the roof may cause the closure of the soil-stack and prevent proper venting. In order to determine the effect of the stoppage of the top of the soil-stack comparative tests were made with the top open and with the top closed. The apparatus used differs from that shown in Fig. 14 only in that no house-trap was used and the outlet of the house-drain was unobstructed. Tests were made on 2-in., 3-in., and 4-in. soil-stacks similarly arranged. Observations of positive and negative pressures were made in unvented traps placed at various levels along the soil-stack.

The pressures observed with the soil-stack closed were much greater and the water in the observed traps oscillated more rapidly than when the soil-stack was open at the top. The pressures in the traps under observation changed rapidly from high positive to high negative pressure. In a number of tests the maximum pressure was four times the minimum. For rates of discharge greater than about 100 gallons per minute the stack shook with the vibrations caused by the recurrent vacuums and positive pressures and their sudden release. The oscillation of the water in the traps under observation was so rapid that for pressures greater than 0.5 to 0.7 ft. the reading could not be reliably made closer than to the nearest one-tenth of a foot. The figures in Table 4 represent the averages of five or more readings under the same conditions; they have therefore been expressed to the nearest one-hundreth of a foot.

The figures in the table show that both negative pressure and positive pressure are increased by stopping up the top of the soil-stack. The increase of positive pressure in a trap 38 ft. below the point of entrance of the water to the 4-in. soil-stack, with a rate of discharge of 259 gallons per minute for 7 seconds, was from about 7¾ in. to more than 2½ ft. of water pressure. The increase in negative pressure in a trap 15 ft. below the point of entrance of the water to the 4-in. soil-stack,

TABLE 4
PRESSURES IN A 4-IN. SOIL-STACK CLOSED AT THE TOP AND IN A SOIL-STACK OPEN AT THE TOP

The pressures are caused by discharges down the soil-stack.

Location of Unvented U-tube or Trap as shown in Fig. 14	Rate of Discharge gallons per minute	Pressures in Feet of Water			
		Soil-Stack Closed at the Top		Soil-Stack Open at the Top	
		Positive Pressure	Negative Pressure	Positive Pressure	Negative Pressure
A = 15 ft. B = 31 ft. C = 2 ft.	259	....	*	0.37	1.32
	228	....	*	0.25	1.18
	182	0.67	*	0.35	0.95
	118	0.30	1.3	0.25	0.61
A = 22 ft. B = 24 ft. C = 2 ft.	259	0.46	1.21	0.51	1.10
	228	0.44	0.79	0.42	0.89
	182	0.76	1.55	0.42	0.87
	118	0.61	1.51	0.31	0.54
A = 38 ft. B = 8 ft. C = 2 ft.	259	†	....	0.65	....
	228	1.70	0.97	0.50	....
	182	0.98	0.36	0.52	....
	118	0.31	0.16	0.32	....
The trap was located 20 ft. from the soil-stack on a 4-in. horizontal waste pipe. It was vented into 16 ft. of 3-in. pipe closed at the upper end. A = 15 ft. B = 31 ft. C = 8 ft.	34	0.005	0.08	0.01	0.03
	48	0.04	0.12	0.03	0.06
	64	0.06	0.13	0.03	0.10
	76	0.05	0.23	0.07	0.22
	108	0.07	0.48	0.15	0.48
	143	0.25	0.94	0.21	0.75
	172	....	‡	0.32	0.98
	207	....	‡	0.30	1.23

*More than 2.2 ft.
†More than 2.5 ft.
‡More than 1.4 ft.

with a rate of discharge of 118 gallons per minute for 7 seconds, was from about 7¼ in. to about 15½ in. of water pressure.

The conclusions reached from a study of these tests are expressed in general terms only, because of the relatively small number of tests and the approximate nature of the readings. It is concluded that as a result of the closure of the top of a soil-stack (a) both positive and negative pressures will be increased; (b) either positive or negative pressure, or both, will be created at points where they would not exist if the top of the stack were open; (c) the pressure caused by one or more water-closets discharging down a 4-in., or smaller, soil-stack, longer than 15 ft.,

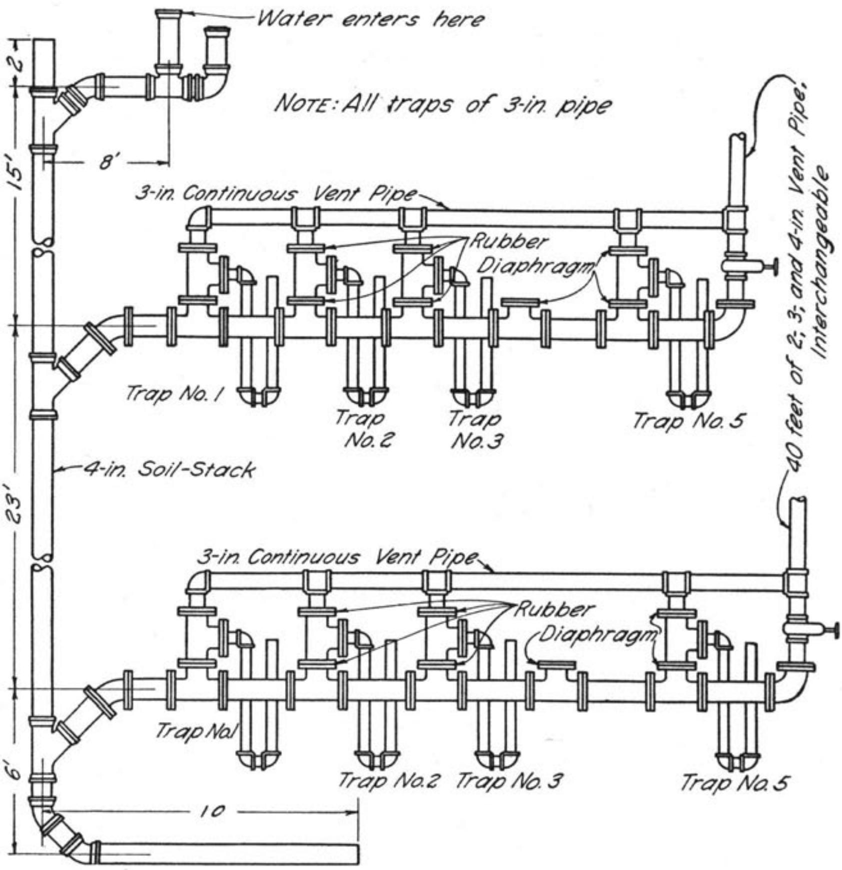


FIG. 18. APPARATUS USED TO DETERMINE THE PRESSURES AT DIFFERENT DISTANCES FROM THE SOIL-STACK AND FOR VARIOUS TYPES OF VENTING

The traps were vented in various ways. The pressures were created by water falling down the soil-stack.

when the top of the soil-stack is closed, is so great as to make probable the breaking of the seal of unvented traps connected to the soil-stack or to pipes connected to the soil-stack.

It is concluded that soil-stacks should be designed so as to prevent the possiblity of becoming stopped up at the top. This is in accord with existing good practice in plumbing design.

21. *The Pressures at Different Distances from the Soil-Stack in Horizontal Waste Pipes, caused by Discharges down the Soil-Stack.*—The

purpose of this series of tests was to determine whether all the traps of a battery of fixtures connected to the same horizontal waste pipe are subject to the same pressure as the result of water discharging down the soil-stack. It is to be noted that these tests do not show the effect of the discharge of one or more fixtures on the trap of another fixture that is connected to the same horizontal waste pipe.

A diagram of the apparatus used in these tests is shown in Fig. 18. The traps were 3 in. in diameter. The tests were made with no vent, continuous vent, and loop vent. In each test the type of venting on all the traps was the same. Two 4-in. horizontal waste pipes were used, one 15 ft. and the other 38 ft. below the point of entrance of water to the soil-stack. The total height of fall of water in the soil-stack was 46 ft. The horizontal waste pipe at the higher level was 20 ft. long with traps spaced 4 ft. apart. The horizontal waste pipe at the lower level was 25 ft. long with traps spaced 5 ft. apart. The tests were made by measuring the change of level of the water in one trap, with all other traps closed off by inserting a rubber diaphragm across the connection between the trap and the waste pipe. In all tests, except when loop venting was being tested, the valve shown near the end of the horizontal waste pipe was closed.

TABLE 5

PRESSURES AT DIFFERENT DISTANCES FROM THE SOIL-STACK IN HORIZONTAL WASTE PIPES

The pressures are caused by discharges down the soil-stack, and are given in feet of water. The observations were made in the horizontal waste pipe at the lower level shown in Fig. 18 except as noted in the last line of the table.

Type of Venting	Rate of Discharge gallons per minute	Distance from the Soil-stack to Point where Pressure was Read in Feet of Water									
		5 feet		10 feet		15 feet		20 feet		25 feet	
		Character of Pressure									
		+	−	+	−	+	−	+	−	+	−
2-in. crown	290	.20	....	.28	....	.20	....	....	....	.30	....
3-in. crown	290	.15	....	....	....	.15	....	....	....	.18	....
4-in. crown	290	.14	....	....	....	.12	....	....	....	.10	....
2-in. loop	290	.14	....	.36	....	.26	....	.29	....	.17	....
3-in. loop	290	.14	....	.20	....	.16	....	.19	....	.15	....
4-in. loop	290	.13	....	.12	....	.10	....	.13	....	.10	....
None	207	1.06	.32	1.40	.44	1.11	.72	.99	.65	1.32	.36
None	207	1.30	.40	1.32	.47	1.47	.30	1.24	.31	....	....
None	207	1.18	....	1.37	....	1.26	....	1.12	....	1.32	....
None*	64	.03	.10	....	....	.02	.12	.06	.13	.04	.18

*The values in the last line of the table were observed at the upper level shown in Fig. 18, and the distances from the soil-stack to the points where the pressure was read were, respectively, 4 ft., 8 ft., 12 ft., 16 ft., and 20 ft.

Typical observations are recorded in Table 5. In studying this table no progressive change in pressure is to be observed as the distance from the soil-stack is increased. It is possible that the use of a smaller diameter or greater length of horizontal waste pipe might reveal a tendency towards progressive change in pressure with increasing distance from the soil-stack, but for the diameters and lengths used in ordinary residences it is probable that no such progressive change would be noted.

It is concluded from all the tests that for 3-in. and 4-in. soil-stacks and 3-in. and 4-in. horizontal waste pipes, and for lengths of horizontal waste pipes up to 25 ft., the pressure in all the traps on the same waste pipe is the same, provided the venting of the traps is the same and the pressure is created by a discharge down the soil-stack. The length of the connection between a trap and the soil-stack does not affect the pressure on the trap within the limits stated.

22. *Tests to Determine the Factors Affecting Self-Siphonage.*—Self-siphonage occurs when water discharging through a trap and through the waste pipe beyond creates sufficient vacuum and passes through the trap with a velocity such that enough water is drawn from the trap to weaken or destroy the seal. The amount of water drawn from the trap may be affected by various factors. The purpose of this series of tests was to determine the nature of these factors, and, if possible, to express their effect quantitatively. The factors studied were the type of the trap, the length of the drop in the waste pipe as shown in Figs. 1 and 19, the depth of the seal, the rate of discharge, and the length of the vertical pipe between the trap and the fixture.

In the preliminary tests it was found that the shape of the fixture and the shape and condition of the trap were conditions which must be standardized for subsequent tests. When a vortex was created as the water discharged from the fixture the seal in the trap usually did not break. If the fixture were so shaped as to allow water to drip into the trap after the vacuum had ceased to exist the seal of course would be restored or strengthened. An irregularly shaped trap, or one with rough surfaces which retarded the flow of water, reduced the weakening of the seal of the trap. In the final tests the formation of a vortex in the fixture was prevented by placing baffles in the fixtures. The traps first used were smooth glass U-tubes with easy curves which gave the least possible obstruction to the passage of water.

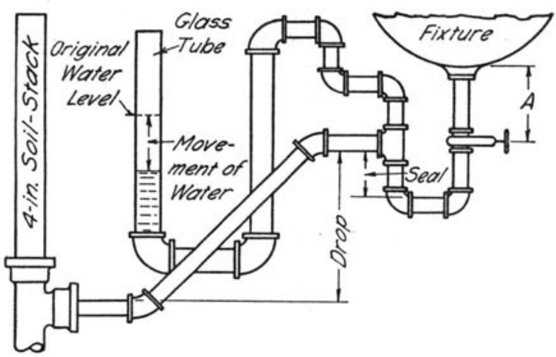


FIG. 19. APPARATUS USED IN SELF-SIPHONAGE TESTS ON UNVENTED TRAPS

TABLE 6

PRESSURES RESULTING FROM THE USE OF DIFFERENT LENGTHS OF DROP, DIFFERENT RATES OF DISCHARGE, AND DIFFERENT DEPTHS OF SEAL IN THE UNVENTED SELF-SIPHONAGE APPARATUS SHOWN IN FIG. 19

The maximum pressure was observed just as the seal broke. In all tests except those noted, the rate of discharge was 18 gallons per minute and a ¾-inch glass trap was used.

Length of Drop feet	Depth of Seal feet	Pressure feet	Length of Drop feet	Depth of Seal feet	Pressure feet
0.00	1.05	0.33	2.40	0.71	0.85
0.48	0.38	0.20	2.40	0.97	0.94
0.92	0.38	0.28	2.40	1.24	1.11
1.75	0.38	0.38	2.62	0.89	0.90
0.76	1.82	1.10	2.62	1.10	1.10
0.98	1.82	1.22	2.62	1.56	1.48
1.32	1.82	1.44	2.62	1.82	1.74
1.80	0.35	0.44	0.81	0.17	0.28*
1.80	0.73	0.62	0.81	0.17	0.32*
1.80	0.90	0.84	0.81	0.17	0.27*
1.80	1.14	1.38	0.81	0.17	0.96*
1.80	1.35	1.62	5.5	0.38	0.25†
2.40	0.32	0.62	5.5	0.38	0.27†
2.40	0.53	0.68	5.5	0.38	0.51†

*In these four tests the friction in the trap was progressively increased by using a trap made up of 1-in. pipe. The lower portion of the trap was a straight nipple with the following lengths: 0.08 ft., 0.22 ft., 0.42 ft., and 1.85 ft.

†In these three tests the rate of discharge was varied as follows: 18 gallons per minute, 22 gallons per minute, and 36 gallons per minute.

Table 7

Pressures Resulting from the Use of Different Lengths and Diameters of Crown Vent and Different Lengths and Diameters of Drop, and from Inserting the Plug in the Outlet of the Fixture at the Moment it Becomes Empty

The apparatus is shown in Fig. 29.

Crown Vent		Drop		Pressure feet	Crown Vent		Drop		Pressure feet
Length feet	Diameter inches	Length feet	Diameter inches		Length feet	Diameter inches	Length feet	Diameter inches	
None	None	0.89	1	1.00*	50	1½	1.25	2	0.15†
1½	¾	0.89	1	0.20*	2	1½	1.25	2	0.14†
None	None	1.35	1	1.41*	0	1½	1.25	2	0.16†
60	¾	1.35	1	0.17*	None	None	1.25	2	1.16‡
1½	¾	1.35	1	0.20*	None	None	1.25	2	1.68¶
None	None	1.25	2	1.32*	Slight§	Slight	0.45	2	0.24*
59	¾	1.25	2	0.13*	Slight§	Slight	0.6	2	0.33*
1½	¾	1.25	2	0.11*	Slight§	Slight	0.9	2	0.36*
50	1½	1.25	2	0.13*	Slight	Slight	1.25	2	0.54*
None	None	1.25	2	1.81†	Slight	Slight	1.75	2	0.60*
59	¾	1.25	2	1.15†	60	1	1.25	2	0.18*
1½	¾	1.25	2	0.91†	3	Slight	1.25	2	0.19*

*The discharge from the fixture was complete and undisturbed. No overflow pipe was used.

†The plug was inserted in the fixture just at the moment the fixture became empty. No overflow pipe was used.

‡The discharge from the fixture was complete and undisturbed. An overflow pipe was used. It was connected to the discharge pipe just below the fixture and was carried up into the fixture just above the highest water level.

¶The plug was inserted in the fixture just at the moment the fixture became empty. An overflow pipe was used. It was connected as stated in the preceding note.

§A valve on the crown vent pipe was open a small amount in these tests.

A diagram of the apparatus used is shown in Figs. 19 and 29. The sloping waste pipe shown was replaced in some tests by a vertical pipe. The glass traps first used were later replaced by traps made of standard threaded pipe and fittings. The glass traps are not shown in the figure. In making a test the trap and the fixture were filled with water, the valve below the fixture was adjusted to give the desired rate of discharge, and then the plug was removed from the fixture. Observations were made during the time the fixture was emptying. When large bubbles of air were seen to pass through the glass trap during a test it was considered that the seal had been broken or weakened. The strengthening of the seal by water dripping from the fixture was not measured as no attention was paid to the amount of water in the trap after a test. Observations were made of the amount of vacuum created at the crown of the trap by reading the manometer connected to the trap at the crown. The movement of the water in the manometer was slow and steady.

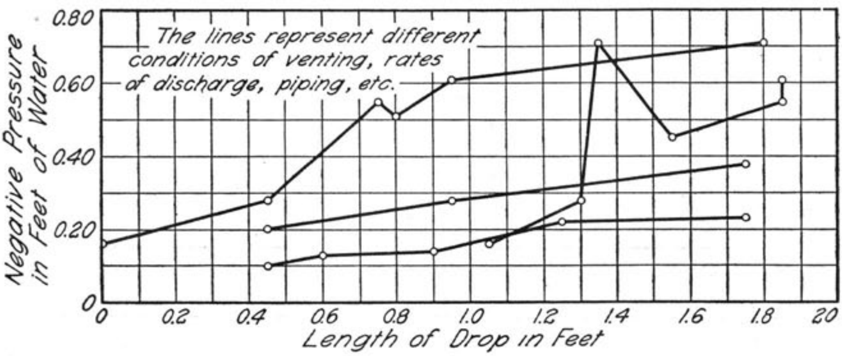


FIG. 20. DROP AND NEGATIVE PRESSURE IN SELF-SIPHONAGE TESTS

The vacuum was built up at an approximately uniform rate until the maximum was just reached as the fixture became empty or the seal was broken. No fluctuations of pressure were observed as in other tests, and the readings could be made easily and accurately. The rates of discharge used in the tests varied between 18 and 45 gallons per minute. Twenty to thirty seconds were required to empty the fixture. The vacuum was built up during this time, and occasionally, when the seal of the trap was not broken, the vacuum would be held in the trap for about twenty seconds until air could enter the trap from the soil-stack through the waste pipe. Some of the readings of vacuums taken under different conditions are recorded in Tables 6 and 7.

The type of the trap was next changed by using a P-trap made up of two vertical legs of iron pipe with standard elbows joined by a piece of horizontal iron pipe. The length of this horizontal pipe was varied in different tests. The pressures observed in typical tests are given in Table 6, together with other information. Since it was no longer possible to see bubbles passing through the trap the pressure reported is the greatest vacuum observed. It is evident from the values in Table 6 that the length of the horizontal pipe connecting the two legs of the trap is an appreciable factor in affecting its resistance to siphonage.

The length of drop, as shown in Figs. 1, 19, and 29, has been plotted in Fig. 20 against the average negative pressure read at the crown of the trap. Various rates of discharge, from 15 to 45 gallons per minute, various piping arrangements and other conditions were tried. It is evident from a study of the lines in Fig. 20 that the negative pressure created at the crown of a trap varies directly as the length of the drop provided all other conditions remain unchanged.

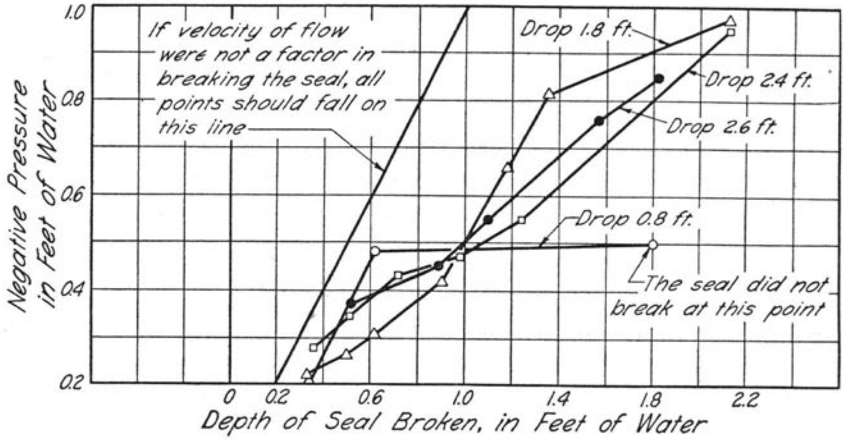


FIG. 21. NEGATIVE PRESSURES AT WHICH AIR WAS FORCED THROUGH DIFFERENT DEPTHS OF SEAL IN THE TRAP SHOWN IN FIG. 19

The amount of negative pressure necessary to break the seal of a trap was found to vary directly with the depth of seal. This is shown in Fig. 21. It is to be noted that the negative pressure produced was always less than the depth of seal broken. This is due probably to the movement of water through the trap assisting in carrying air with it. As the depth of seal in a trap is increased without change of drop or other conditions it is evident that some depth will be reached at which air will not pass through the trap. It is also evident that after a depth of seal has been reached such that air is not drawn through the trap the negative pressure at the crown of the trap will not increase with increasing depths of seal, with the same rate of discharge, length of drop, etc. This is shown by the line in Fig. 21 marked "drop 0.8 ft." The maximum negative pressure produced with this drop was 0.5 ft. with a depth of seal of about 1.0 ft. Five such depths of seal with the corresponding drop are listed in Table 8.

It may be seen from Table 8 that air will pass through an unvented trap arranged as in this test and having a 4-in. (0.33 ft.) seal when there is no drop in the waste pipe. It may be seen also that air will pass through a trap, that is, the trap will siphon itself, when it is arranged as in this test, with a drop in the waste pipe about three-fourths as large as the depth of seal in the trap. This can be explained by considering that the velocity of the water flowing through the discharge pipe increased the vacuum resulting from the drop in the pipe. The increase in vacuum

TABLE 8

DEPTHS OF SEAL IN AN UNVENTED TRAP WHICH ARE JUST STRONG ENOUGH TO RESIST SELF-SIPHONAGE WHEN THE DROP IN THE WASTE PIPE IS AS SHOWN IN FIG. 19

The rate of discharge was not measured.

Drop feet	Depth of Seal feet
.00	.33
.25	.56
.50	.78
.75	1.01
1.00	1.24

caused in this manner is shown by the readings of negative pressure, at the crown of the trap, given in Fig. 21. In this figure the vacuum is always greater than the equivalent drop. The same thing is shown by the tests in which the drop was held constant and the velocity of the water in the discharge pipe (rate of discharge) was increased. The readings of pressure made in these tests are recorded in Fig. 22 and in Table 6.

The length of the vertical pipe between the trap and the fixture, distance *A* in Fig. 19, was shown to have no effect on the pressures produced in the trap when the rate of discharge was unchanged. Ordinarily, when this length is increased the rate of discharge will be increased unless some obstruction is offered to the flow of water through the pipe.

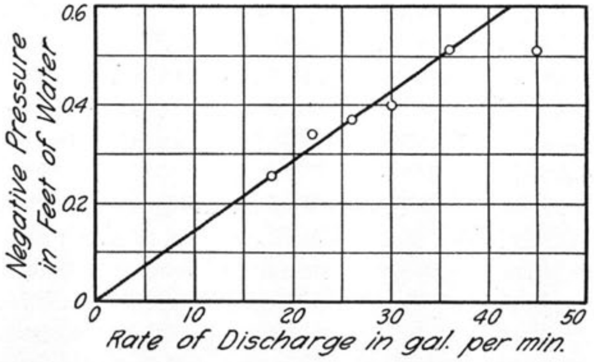


FIG. 22. NEGATIVE PRESSURES AT THE CROWN OF THE TRAP AND RATE OF DISCHARGE FOR THE APPARATUS SHOWN IN FIG. 19

The conclusions reached from the studies on self-siphonage are that either for unvented traps, as shown in Fig. 19, or for vented traps, as shown in Fig. 29:

(1) The resistance of a trap to self-siphonage is increased by impeding the flow of water through the trap. This can be done by putting baffles in the trap, causing vortices, roughening the sides of the trap, and by other means. The objections to these expedients from a sanitary viewpoint are stated in Chapter IV.

(2) The resistance of a trap to self-siphonage varies with the depth of seal in the trap, other conditions remaining unchanged. Doubling the depth of seal will double the negative pressure required to break the seal.

(3) The negative pressure produced in a trap when water is discharging through it varies with the rate of discharge, provided all other conditions remain unchanged. Some values for this negative pressure for different rates of discharge are given in Table 6.

(4) The negative pressure produced in a trap when water is discharging through it varies with the drop in the discharge pipe, provided all other conditions remain unchanged. Some negative pressure is produced with no drop in the waste pipe; hence, doubling the drop will not double the negative pressure produced. Some values of this negative pressure for different drops are given in Table 6.

(5) The negative pressure 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 constant. An increase in the length of this pipe will ordinarily increase the rate of discharge, which will result in an increase of the negative pressure produced in the trap.

(6) The destruction or weakening of the seal of the trap can be prevented by venting. A method for determining the proper vents to use is explained in Chapter III. The destruction or weakening of the trap seal by self-siphonage will be prevented when the fixture is so constructed that after the seal of the trap has broken sufficient water will fall into the trap to restore the seal.

23. *The Effect of Mixing Solid Matter with the Discharge from a Water-Closet on the Pressures in a Plumbing System.*—The discharges from water-closets usually contain solid matter which may have an

effect on the pressures created in a plumbing system. In order that the conclusions reached from studies of tests made with clean water in clean pipes might be rendered of general application it was necessary to study the effect on the pressures in a plumbing system by mixing solid matter with the water discharged.

The solid matter used in each test consisted of a wad of cotton waste which would just pass through the pipes. Each wad formed an almost air-tight piston which fitted the pipes so closely that it became stuck occasionally resulting in difficulty in cleaning the pipe. The wads were inserted into the waste pipes through a hand-hole immediately below the fixture to be discharged. They were pushed through the pipes by the water discharging from the fixture. It is to be expected that such wads of solid matter would produce pressures much greater than those produced by water alone, and also greater than the pressures which would be produced by the ordinary mixtures of solid and liquid matter discharged from a water-closet.

The tests were made in the same manner as the tests to determine the proper diameter and length of vent pipe to use under different conditions, as described in Section 24, the only difference being that wads of solid matter were used.

Typical test results are given in Tables 9 and 10. It will be noted in these tables that the wad of cotton waste materially increased the pressures produced at low discharges. For large rates of discharge the presence of the wad of cotton waste had no appreciable effect on the pressures produced. For example, no effect was produced on the pressures in a 3-in. soil-stack by the wad of cotton waste with discharges of more than 120 to 150 gallons per minute. It was noted that near the bottom of the stack the increase in the negative pressure was greater than the increase in the positive pressure and that the negative pressure appeared before the positive pressure. The positive pressure was not caused by the compression of the air ahead of the falling wad, as no positive pressure appeared until after the wad had been felt and heard to strike the bottom of the soil-stack. The positive pressure developed suddenly, it was of short duration, and its intensity was determined apparently by the amount of resistance encountered by the solid matter in passing around the bend at the bottom of the soil-stack.

The tests described in Sections 10 to 22 were made to permit the study of the causes underlying the pressures created in plumbing systems and the principles controlling them. The tests could not have been

TABLE 9

THE EFFECT OF MIXING SOLID MATTER WITH THE DISCHARGE FROM A WATER-CLOSET ON THE PRESSURES IN A 4-IN. SOIL-STACK

No house-trap was used in any test.

Crown Vent		Discharge gallons per minute	With or Without Solid Matter	Pressure in Feet						Ratio of Maximum to Average Pressure Read		Ratio of Maximum Pressure with Solid Matter to Average Pressure without Solid Matter
				Maximum		Average		Minimum				
Diameter inches	Length feet			Positive	Negative	Positive	Negative	Positive	Negative	Positive Pressure	Negative Pressure	
None	None	30	with	0.18	0.11	0.11	0.09	0.07	0.05	1.6	1.6	2.3*
None	None	30	without	0.12	....	0.08	....	0.05	....	1.5	....	....*
None	None	118	with	0.25	0.20	0.20	0.11	0.14	0.05	1.3	1.8	....*
1	20	30	with	0.14	0.09	0.12	0.07	0.09	0.07	1.2	1.3	....*
1	20	118	with	0.18	0.17	0.16	0.15	0.15	0.10	1.1	1.1	....*
2	20	30	with	0.06	0.05	0.04	0.03	0.03	0.02	2.0	1.7	....*
2	20	118	with	0.07	0.07	0.07	0.06	0.06	0.05	1.0	1.2	....*
3	20	30	with	0.03	0.03	0.02	0.02	0.01	0.02	1.5	1.5	....*
3	20	67	with	0.03	0.03	0.03	0.02	0.02	0.01	1.0	1.5	....*
3	20	118	with	0.06	0.05	0.04	0.04	0.03	0.03	1.5	1.3	....*
None	None	30†	with	0.39	0.10	0.37	0.04	0.34	0.00	1.1	2.5	....‡
None	None	30	with	0.18	0.12	0.09	0.08	0.06	0.04	2.0	1.5	....‡
None	None	67	with	0.24	0.13	0.15	0.10	0.09	0.06	1.6	1.3	....‡
None	None	118	with	0.38	0.28	0.23	0.16	0.14	0.08	1.7	1.8	....‡
None	None	30	with	0.07	0.22	0.04	0.17	0.01	0.13	1.8	1.3	....¶
None	None	67	with	0.13	0.42	0.05	0.24	0.02	0.14	2.6	1.8	....¶

*In these tests the water fell 42 ft. in the soil-stack above the point where the pressure was read.
†The outlet from the soil-stack was submerged 1½ in. in this test. In all other tests the outlet was open without obstruction.
‡In these tests the water fell 38 ft. in the soil-stack above the point where the pressure was read.
¶In these tests the water fell 15 ft. in the soil-stack above the point where the pressure was read.

TABLE 10

THE EFFECT OF MIXING SOLID MATTER WITH THE DISCHARGE FROM A WATER-CLOSET ON THE PRESSURES IN A 3-IN. SOIL-STACK

No house-trap was used in any test. The water fell 42 ft. in the soil-stack above the point where the pressure was read.

Crown Vent		Discharge gallons per minute	With or Without Solid Matter	Pressure in Feet						Ratio of Maximum to Average Pressure Read		Ratio of Maximum Pressure with Solid Matter to Average Pressure without Solid Matter
				Maximum		Average		Minimum				
Diameter inches	Length feet			Positive	Negative	Positive	Negative	Positive	Negative	Positive Pressure	Negative Pressure	
None	None	30	with	0.33	....	0.16	....	0.08	....	2.1	....	4.7
None	None	30	without	0.08	....	0.07	....	0.06	....	1.1	....	
None	None	118	with	0.74	....	0.61	....	0.49	....	1.2	....	1.3
None	None	118	without	0.63	....	0.57	....	0.51	....	1.1	....	
¾	50	30	with	0.20	....	0.15	....	0.12	....	1.3	....	2.9
¾	50	30	without	0.08	....	0.07	....	0.06	....	1.1	....	
¾	50	118	with	0.65	....	0.52	....	0.40	....	1.2	....	1.4
¾	50	118	without	0.50	....	0.46	....	0.42	....	1.1	....	
¾	10	30	with	0.14	....	0.11	....	0.07	....	1.3	....	2.3
¾	10	30	without	0.07	....	0.06	....	0.05	....	1.2	....	
¾	10	118	with	0.38	....	0.32	....	0.24	....	1.2	....	1.2
¾	10	118	without	0.38	....	0.33	....	0.31	....	1.2	....	
1	50	30	with	0.23	....	0.14	....	0.05	....	1.6	....	3.8
1	50	30	without	0.08	....	0.06	....	0.06	....	1.3	....	
1	50	118	with	0.47	....	0.36	....	0.27	....	1.3	....	1.4
1	50	118	without	0.36	....	0.33	....	0.28	....	1.1	....	
1	10	30	with	0.12	....	0.09	....	0.07	....	1.3	....	3.0
1	10	30	without	0.04	....	0.04	....	0.03	....	1.0	....	
1	10	118	with	0.29	....	0.21	....	0.14	....	1.4	....	1.6
1	10	118	without	0.20	....	0.18	....	0.15	....	1.1	....	
1½	36	30	with	0.19	....	0.13	....	0.08	....	1.5	....	4.8
1½	36	30	without	0.04	....	0.04	....	0.03	....	1.0	....	
1½	36	118	with	0.16	....	0.11	....	0.06	....	1.5	....	1.3
1½	36	118	without	0.13	....	0.12	....	0.11	....	1.1	....	
2	0	30	with	0	....	0	....	0	....	1.0	....	1.0
2	0	30	without	0	....	0	....	0	....	1.0	....	

made successfully with a mixture of solid matter and water, but in drawing conclusions of value in plumbing design a knowledge of the effect of solid matter on the pressures created is essential. Conclusions reached with regard to the effect on the pressures in a plumbing system of mixing solid matter with the discharges down a soil-stack and also with regard to the proper size of vent pipes to use under different conditions are given in Section 24.

24. *The Pressures in Traps Vented in Different Ways with Vent Pipes of Different Diameters and Lengths.*—The determination of the size and length of vent pipes is as important in securing economy and satisfaction as any other matter which must be settled in plumbing design. The formulation of a method for determining sizes and lengths of vent pipes was, therefore, one of the principal aims of this work. The tests were divided into three series according to the type of apparatus used and the purpose of the test. The first series was conducted to study the pressures created in various places by water falling down the soil-stack; the second to study the pressures created in one trap by the discharge of a fixture through another trap into the same horizontal waste pipe; and the third to study the pressures created by self-siphonage in vented traps. Continuous venting, crown venting, loop venting, and vents formed of closed chambers attached to the discharge leg of the trap just beyond the crown were studied in these tests.

The apparatus used for the first series is shown in Fig. 5. The arrangement of the piping is such that the relief given by crown, continuous, or loop venting would be the same. Water entered the apparatus at the point *A*. Pressures created in traps 42 ft. below *A* with a 4-in. soil-stack, and 15 and 38 ft. below *A* with a 3-in. soil-stack, were observed. With the 4-in. soil-stack the rates of discharge were 67, 129, and 259 gallons per minute for 7 seconds. The sizes of vent pipes were $\frac{3}{4}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 in. For each diameter of vent pipe eight lengths, ranging from 0 to 100 ft., were used. With the 3-in. soil-stack the rates of discharge were 30, 67, and 118 gallons per minute for 7 seconds. The sizes of vent pipes were 1, $1\frac{1}{2}$, and 2 in. For each diameter of vent pipe four to six lengths ranging from 0 to 50 ft. were used. Each test was repeated from five to twenty times. In some cases a wad of cotton waste which would just pass through the waste pipe and soil-stack was inserted in the waste pipe just below the point *A* of Fig. 5.

The pressures observed in some of the tests under different conditions of venting and rates of discharge, both with and without the use of solid matter in the discharge, are recorded in Tables 9, 10, and 11. The data in these and similar tables were used in devising a method for the determination of the size and length of vent pipes in plumbing design. The method is explained in Chapter III.

In order to study the relative efficiency of crown or continuous venting and loop venting in relieving the pressures in traps caused by water falling down the soil-stack the arrangement of piping shown in Fig. 18 was set up in addition to the apparatus shown in Fig. 5. The readings of pressure with this arrangement were made on one trap at a time with only one type of vent open; the connections to all other traps and to the crown or loop vent pipe not in use for the particular test were closed off by rubber diaphragms. The pressure in each trap was read with about 40 ft. of 2-in., 3-in., or 4-in. loop vent or with the same length and diameters of crown or continuous vent. The water entered the 4-in. soil-stack at rates up to 290 gallons per minute for 7 seconds. It fell 42 ft. in the soil-stack before passing the end of the horizontal waste pipes to which the traps were connected. No tests were made with solid matter mixed with the water.

Summarized or representative values of pressures obtained are given in Table 5. It was concluded from these tests that continuous or crown venting and loop venting are equally effective in relieving the pressures created in traps by water falling down the soil-stack.

For the second series of tests, to study the pressures created in a vented trap by the discharge of a fixture on the same horizontal waste pipe, the apparatus is shown in Figs. 23 to 28 inclusive. Figure 23 represents the conditions when one or more water-closets are discharged into the same horizontal waste pipe and where the readings of pressure are taken in a trap connected to the horizontal waste pipe between the soil-stack and the discharging water-closets. Figure 24 represents the conditions when the water-closets discharging are between the soil-stack and the trap in which the pressures are read. Figures 25, 26, 27, and 28 represent slight differences in the arrangement of the piping. In Figs. 23 and 24 the vent pipe in some tests was closed at the crown of the trap, in other tests the vent was closed at the valve shown, and in still other tests the vent was open throughout its length. No venting was used in the arrangements of piping shown in Figs. 25 and 26. The arrangement of piping shown in Figs. 27 and 28 provides for loop venting, continuous venting, or crown venting. The positions of the fixture and of the trap in which readings of pressure were made, as shown in Fig. 27, were interchanged in the arrangement shown in Fig. 28.

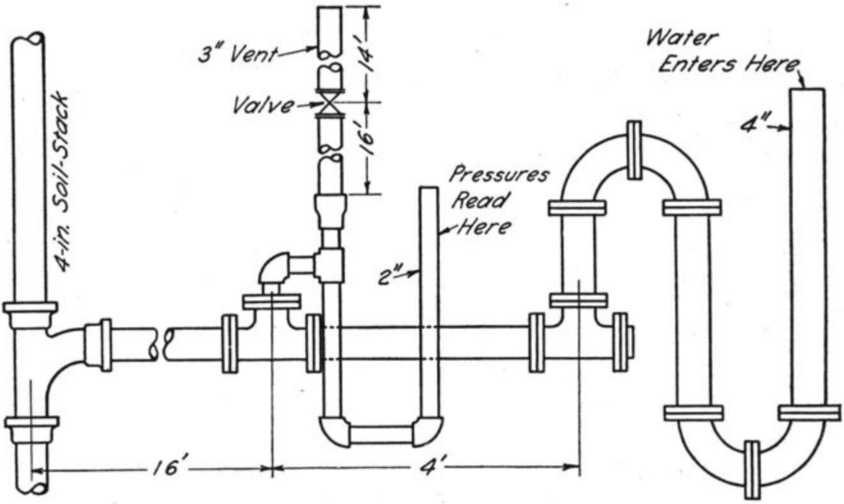


FIG. 23. APPARATUS USED FOR STUDY OF PRESSURES IN A TRAP RESULTING FROM DISCHARGES INTO THE 4-IN. HORIZONTAL WASTE PIPE TO WHICH THE TRAP IS CONNECTED

The trap is located between the soil-stack and the point of entrance of water to the waste pipe

Summarized or representative values of the pressures observed with these different arrangements of piping and points of entrance of water to the piping are given in Tables 6, 7, 8, 12, 13, 14, and 15.

With the pipes arranged as shown in Fig. 23, with the vent closed at the crown of the trap, no positive pressure was observed until the flow of water became sufficient to fill the waste pipe and to cover the outlet end of the trap at which observations were being made. The accumulation of water in the waste pipe is probably sufficiently slow to push the air into the soil-stack without producing observable pressures until the outlet end of the trap is sealed, but after this occurred positive pressure developed in the trap. It was concluded, as a result of the tests made on an unvented trap, that a discharge at a rate of 100 gallons per minute for 7 seconds through a 4-in. waste pipe would cause a positive pressure of less than 2 in. of water in the trap at which observations were made. A discharge at a slightly lower rate would not fill the waste pipe and hence would cause no positive pressure in the trap. The positive pressure created by discharges at a rate higher than 100 gallons per minute for 7 seconds would depend on the manner in which the water backed up in the horizontal waste pipe. Negative pressure is produced

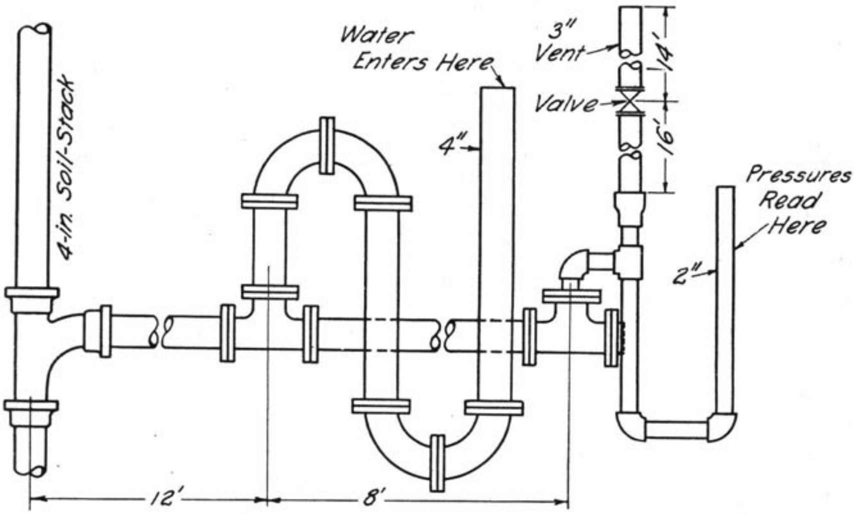


FIG. 24. APPARATUS USED FOR STUDY OF PRESSURES IN A TRAP RESULTING FROM DISCHARGES INTO THE 4-IN. HORIZONTAL WASTE PIPE TO WHICH THE TRAP IS CONNECTED

The water enters the horizontal waste pipe between the soil-stack and the trap where the pressures are measured.

in the observed trap by rates of discharge less than 100 gallons per minute. A rate of 80 gallons per minute caused a negative pressure of 0.25 ft. and smaller rates caused smaller negative pressures. A rate of 185 gallons per minute, however, caused a negative pressure of 1.6 ft. No general expression has been found for the relation between the rate of discharge and the resulting pressure in the trap.

With the pipes arranged as shown in Fig. 24, with the vent closed at the crown of the trap, the positive pressure created is relatively large but the negative pressure is so small as to be negligible for consideration in plumbing design. The positive pressure was apparently caused by water flowing up the horizontal waste pipe and covering the outlet end of the trap in which pressure was being observed. A rate of discharge of 80 gallons per minute for 7 seconds created a positive pressure of 0.25 ft. Higher rates of discharge would probably cause higher positive pressures in a trap located where the readings of pressure were made. Summarized or representative values of the pressures read with the piping arrangements shown in Figs. 23 and 24, without vent, are given in Tables 11 and 12.

TABLE 11

PRESSURES OBSERVED IN TRAPS WITH DIFFERENT SIZE CROWN VENTS

The pressures are caused by different rates of discharge falling 42 ft. down 3-in. and 4-in. soil-stacks.

Diameter Soil-Stack inches	Rate of Discharge gallons per minute	Length of Vent Pipe feet	Pressures in feet for					
			¾-in. Crown Vent	1-in. Crown Vent	1½-in. Crown Vent	2-in. Crown Vent	2½-in. Crown Vent	3-in. Crown Vent
4	67	0–5	0.10	0.07	0.04	....	....	....
4	67	25–30	0.11	0.12	0.08	....	0.03	0.03
4	67	50–60	0.15	0.13	0.08	....	0.06	0.03
4	67	90–100	0.14	0.13	0.11	0.10	0.08	0.05
4	129	0– 5	0.20	0.14	0.06	....	....	....
4	129	25–30	0.28	0.27	0.18	....	0.07	0.04
4	129	50–60	0.30	0.28	0.20	....	0.12	0.11
4	129	90–100	0.32	0.31	0.28	....	0.17	0.12
4	259	0	0.28	0.14	0.03	0.01	....	....
4	259	4– 5	0.61	0.37	0.14	0.05	0.03	....
4	259	25–30	0.95	0.70	0.32	0.24	0.11	0.08
4	259	50–60	0.93	0.73	0.50	0.34	0.20	0.16
4	259	90–100	1.04	0.84	0.57	0.45	0.36	....
3	30	0–5	0.05	0.03	....	....	....	....
3	30	20–25	0.06	0.05	0.03	0.02	....	....
3	30	45–50	0.07	0.06	0.04	0.02	....	....
3	118	0–5	0.27	0.11	....	0.01	....	....
3	118	20–25	0.39	0.23	0.07	0.03	....	....
3	118	45–50	0.46	0.33	0.12	0.06	....	....

The pressure with a 4-in. soil-stack and a discharge of 259 gallons per minute, with no vent, was 1.42 feet.

In Figs. 23 and 24 the arrangement of piping shows only one 2-in. and one 4-in. trap. Water was discharged through the 4-in. trap at rates equal to the simultaneous discharge from one to ten water-closets so that the conclusions drawn are applicable to batteries of one to ten water-closets connected to the same horizontal waste pipe.

The conclusions reached from the observations made on the pressures created with the pipes arranged as shown in Figs. 23 and 24 are:

(a) The discharge of one water-closet will not force the air through 2-in. seals in unvented traps on fixtures connected to the same 4-in. horizontal waste pipe between the soil-stack and the discharging water-closet.

(b) The discharge of one water-closet will not force the air through 2-in. seals in unvented traps on fixtures connected at points on the same 4-in. horizontal pipe farther away from the soil-stack than the discharging water-closet.

TABLE 12

PRESSURES IN A 4-IN. HORIZONTAL WASTE PIPE

Pressures were caused by different rates of discharge into the waste pipe. The tests were made with the apparatus shown in Fig. 23. The water column in the trap at which readings of pressure were taken rose slowly, as though the waste pipe were filling. No positive pressure was noticed until the water level in the waste pipe had apparently reached the outlet of the trap at which readings were being taken.

Rate of Discharge gallons per minute	Pressure in Feet of Water Observed in 2-in. Trap with 9-in. Seal						Remarks
	Positive Pressure			Negative Pressure			
	Max.	Av.	Min.	Max.	Av.	Min.	
50	0	0	0	0	0	0	Loop vented through 30 feet of 3-in. pipe.
64	0	0	0	0	0	0	
185	0.32	0.27	0	0.46	0.38	0.28	
235	0.94	0.86	0.80	0.66	0.57	0.50	
270	1.50	1.50	1.50	0.44	0.44	0.44	
29	0	0	0	0.02	0.02	0.01	Crown vented through 30 feet of 3-in. pipe.
64	0	0	0	0.03	0.01	0.01	
185	0.04	0.02	0.02	0.04	0.03	0.02	
270	0.04	0.02	0	0.04	0.03	0.02	
50	0	0	0	0.34	0.03	0	Crown vented into a closed chamber made of 16 ft. of 3-in. pipe closed at upper end.
65	0	0	0	0.50	0.07	0.01	
185	....	0.46	....	....	1.60	....	

(c) If two or more water-closets are connected to the same horizontal 4-in. waste pipe the traps on all the water-closets and fixtures connected to the same waste pipe should be vented to prevent the breaking of the seal.

The effectiveness of using closed air chambers as vents was tested by closing the valve shown on the vent pipes in Figs. 23 and 24, and by placing a cap on the end of the vent pipe shown in Fig. 5. Representative values of the pressures observed under these conditions are given in Table 15, and show the ineffectiveness of closed air chambers as vents. These values, together with other pressures observed but not recorded in the table, are in accord with the expectation that the use of closed air vents is not practicable. As explained previously, a positive or negative pressure of 2 in. of water will change the volume of the confined air only about one two-hundredth of itself; therefore, in order that an air chamber may act effectively as a vent it will require a volume two hundred times greater than the confined air. It is not possible to state the volume of the confined air with accuracy but it is evident that the

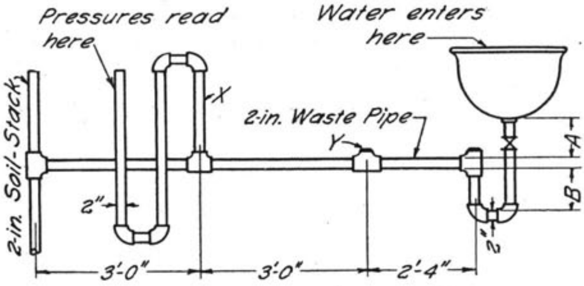


FIG. 25. APPARATUS USED FOR STUDY OF PRESSURES IN A TRAP RESULTING FROM DISCHARGES INTO THE 2-IN. HORIZONTAL WASTE PIPE TO WHICH THE TRAP IS CONNECTED

The trap is located between the soil-stack and the point of entrance of water to the waste pipe.

volume of an air chamber must be large to act effectively as a vent. It is concluded, therefore, that the use of closed air chambers for venting traps is impracticable.

The pressures observed in traps connected to the same horizontal waste pipe were studied further with a 2-in. waste pipe and smaller rates of discharge. The piping arrangement used is shown in Figs. 25 and 26. It was expected that the lengths of the pipes marked *A*, *B*, and *C* would have some effect on the results obtained. These lengths were therefore varied to learn their effect.

It was concluded from these tests that the negative pressure in the trap connected at X for the piping arrangement shown in Fig. 25 varies with the rate of discharge, other conditions remaining unchanged, and varies with the length *B* but is not affected by the length *A*.

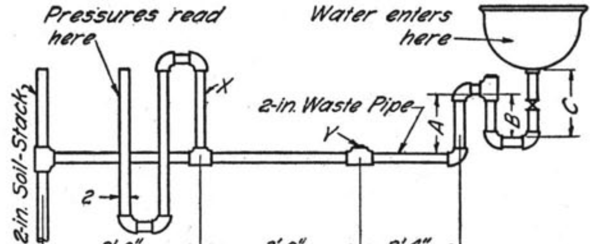


FIG. 26. APPARATUS USED FOR STUDY OF PRESSURES IN A TRAP RESULTING FROM DISCHARGES INTO THE 2-IN. HORIZONTAL WASTE PIPE TO WHICH THE TRAP IS CONNECTED

The piping arrangement is slightly different from that shown in Fig. 25.

TABLE 13

PRESSURES IN A 4-IN. HORIZONTAL WASTE PIPE

The pressures were caused by discharges into the waste pipe. The tests were made on the apparatus shown in Fig. 24.

Rate of Discharge gallons per minute	Pressure in Feet of Water Observed in 2-in. Trap with 9-in. Seal						Remarks
	Positive Pressure			Negative Pressure			
	Max.	Av.	Min.	Max.	Av.	Min.	
50 64	0.02 0.02	0.02 0.01	0.02 0.01	0.02 0.04	0.02 0.02	0.02 0.0	Loop vented through 30 feet of 3-in. pipe.
64 255	0.36 0.01	0.12 0.01	0.04 0.01	0.04 0.02	0.02 0.01	0.01 0.01	Continuous vented into closed chamber made of 16 ft. of 3-in. pipe closed at the upper end.
255	1.0	1.0	1.0	1.5	1.5	1.5	No vent. Top of soil-stack plugged. The vacuum held momentarily and broke with a loud sucking noise.

It was concluded also that the negative pressure in the trap connected at X, for the piping arrangement shown in Fig. 26, varies with the rate of discharge, other conditions remaining unchanged; also with the lengths *A* and *B*, reducing as *B* is increased and increasing as *A* is increased; and is not affected by the length *C*.

Crown or continuous venting and loop venting were studied in tests with the piping arrangements shown in Figs. 18, 27, and 28. Summarized or representative values of the pressures read in some of these tests are given in Tables 12, 13, and 14.

The following conclusions were drawn from these tests:

(a) Crown or continuous venting is the best method of venting to safeguard the seal of traps against breaking due to pressures created by the discharge of fixtures on the same horizontal waste pipe. Loop venting, under such conditions, is valueless.

(b) Negative pressure, in vented or unvented traps, varies with the rate of discharge, with the drop, *A*, in the waste pipe, and with the seal of the trap, *B*.

(c) Positive pressure is produced in unvented traps only when the horizontal waste pipe runs full. This was indicated by the tests in which a discharge at the rate of at least 100 gallons per minute

Table 14

Pressures Resulting from the Use of Different Types and Capacities of Vents and Different Rates of Discharge in the Self-Siphonage Apparatus Shown in Figs. 27 and 28

Pressures are given in feet of water. The vent pipes were 1 in. in diameter except as noted. The drop was 2 ft., the seal was 0.38 ft. and the length of the discharge pipe between the fixture and the trap was 1½ ft. The discharge from the fixture lasted from 6 to 12 seconds. The readings were taken at the moment the fixture became empty. The waste pipe ran full and the trap seal did not break.

Discharge gallons per minute	Type of Vent	Length of Vent feet	Piping Arranged as Shown in Fig. 27						Piping Arranged as Shown in Fig. 28					
			Positive Pressure			Negative Pressure			Positive Pressure			Negative Pressure		
			Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.
30	Crown	50		Negligible			Negligible		0.14	0.11	0.05	0.07	0.06	0.04
18	Crown	50		Negligible			Negligible		0.03	0.01	0	0.02	0.02	0.01
30	Crown	30	0	0	0	0.02	0.02	0.02	0.12	0.10	0.06	0.06	0.05	0.04
18	Crown	30	0.04	0.04	0.03	0.03	0.03	0.02	0	0	0	0.02	0.02	0.02
30	Crown	17	....	0	....	....	0	....	0.04	0.04	0.03	0.03	0.03	0.02
18	Crown	17	....	....	....	....	....	....	0	0	0	....	0.01	....
30	Loop	52	0.90	0.84	0.80	0.34	0.30	0.26	1.2	1.10	0.86	0.42	0.36	0.32
18	Loop	52	0.32	0.31	0.30	0.34	0.30	0.28	0.26	0.23	0.20	0.36	0.30	0.24
30	Loop	32	0.86	0.83	0.80	0.32	0.29	0.24	1.18	1.10	1.02	0.44	0.38	0.30
18	Loop	32	0.38	0.33	0.28	0.34	0.30	0.22	0.20	0.18	0.16	0.30	0.26	0.20
30	Loop	31	....	....	....	....	....	....	1.18	1.15	1.12	0.22	0.19	0.16
18	Loop	31	....	....	....	....	....	....	0.22	0.19	0.16	0.24	0.22	0.20
30	Loop	21	0.90	0.82	0.78	0.38	0.32	0.24	0.40	0.13	0.13	0.30	0.25	0.20
18	Loop	21	0.28	0.25	0.20	0.36	0.31	0.24	0.38	0.35	0.28	0.36	0.29	0.26
30	Loop	15½	0.84	0.82	0.80	0.40	0.35	0.32	....	....	....	....	....	....
18	Loop	15½	0.36	0.33	0.28	0.40	0.33	0.30	....	....	....	....	....	....
30	Loop	4½	0.88	0.86	0.84	0.32	0.31	0.28	....	....	....	....	....	....
30	Loop*	59	0.82	0.78	0.74	0.40	0.34	0.30	....	....	....	....	....	....
30	Loop*	5	0.80	0.78	0.76	0.38	0.32	0.30	....	....	....	....	....	....
30	Crown*	60	....	....	....	....	....	....	0.06	0.04	0	0.13	0.11	0.08
30	Crown*	30	....	....	....	....	....	....	0.05	0.04	0.03	0.08	0.07	0.05
30	Crown*	0	....	....	....	....	....	....		Negligible			Negligible	
30	No vent	..	....	....	....	0.58	0.51	0.42	0.86	0.84	0.80	0.56	0.40	0.46
18	No vent	..	....	....	....	0.55	0.45	0.28	....	....	....	....	....	....

*The diameter of the vent pipe used in this case was ¾ in.

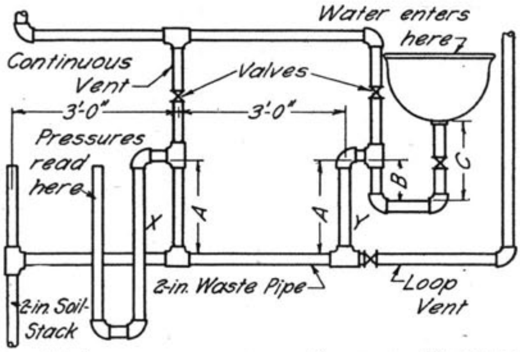


FIG. 27. APPARATUS USED FOR STUDY OF PRESSURES IN A TRAP RESULTING FROM DISCHARGES INTO THE 2-IN. HORIZONTAL WASTE PIPE TO WHICH THE TRAP IS CONNECTED

The piping arrangement differs from that shown in Fig. 26 in that the traps are vented.

for about 7 seconds into a 4-in. horizontal waste pipe on a slope equal to or greater than ¼ in. per foot was required to produce a positive pressure 4 ft. from the point of entrance of water into the waste pipe, measured towards the soil-stack. Smaller rates of discharge produced no positive pressure. A discharge at the rate of 18 gallons per minute for about 30 seconds into a 2-in. waste pipe, on a slope of ¼ in. per foot, produced positive pressure 3 ft. from the point of entrance of water into the waste pipe, measured towards the soil-stack. The minimum rate of discharge which produced positive pressure in the 2-in. waste pipe was not determined.

TABLE 15

PRESSURES OBSERVED IN TRAPS CROWN VENTED INTO CLOSED AIR CHAMBERS

The pressures are caused by different rates of discharge falling 42 ft. down a 4-in soil-stack.

Discharge gallons per minute	Length of Air Chamber feet	Pressures in Feet for Air Chambers		Pressures in Feet with No Vent
		3-in. Diam.	¾-in. Diam.	
67	0–5	....	....	0.15
	25–30	0.16	0.14	
	50–60	0.16	0.14	
	90–100	....	0.15	
129	0–5	....	....	0.35
	25–30	0.38	0.36	
	50–60	0.41	0.39	
	90–100	0.34	0.36	

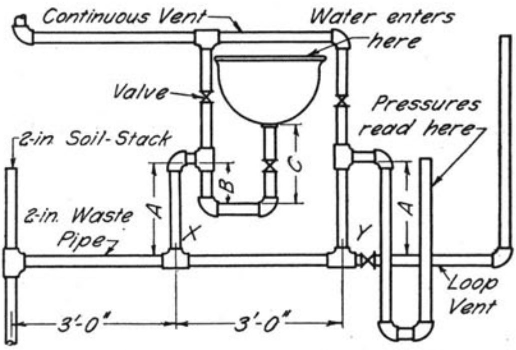


FIG. 28. APPARATUS USED FOR STUDY OF PRESSURES IN A TRAP RESULTING FROM DISCHARGES INTO THE 2-IN. HORIZONTAL WASTE PIPE TO WHICH THE TRAP IS CONNECTED

The piping arrangement differs from that shown in Fig. 27 in that the water enters the waste pipe between the soil-stack and the trap in which the pressures are measured.

(d) The positive pressure produced in unvented traps by the discharge of other fixtures on the same horizontal waste pipe varies with the vertical distance of the discharging fixture above the waste pipe; i.e., the distance *A* in Fig. 25.

(e) The pressures, both positive and negative, produced in an unvented trap connected at X in Figs. 25 and 26 with the fixture discharging into the horizontal waste pipe at *Y* are the same as the pressures produced in an unvented trap connected at *Y* with the fixture discharging into the horizontal waste pipe at X.

(f) Any size of crown or continuous vent ¾ in. or larger will prevent pressures greater than 2 in. in traps arranged as shown in Figs. 27 and 28 with the following limitations: (1) If the vent is ¾ in. in diameter it must be less than 60 ft. long. It may be longer if the diameter is greater. (2) The rate of discharge must be less than 30 gallons per minute. (3) The waste pipe must be 2 in. in diameter or smaller.

(g) The pressures created in a vented trap by the discharge of a fixture connected to the same horizontal waste pipe will be less than the pressure created in a vented trap by the same rate of discharge down a soil-stack, provided the venting is the same in each case.

For the third series of tests, to study the pressures created in vented traps by self-siphonage, the apparatus used is shown in Fig. 29. In

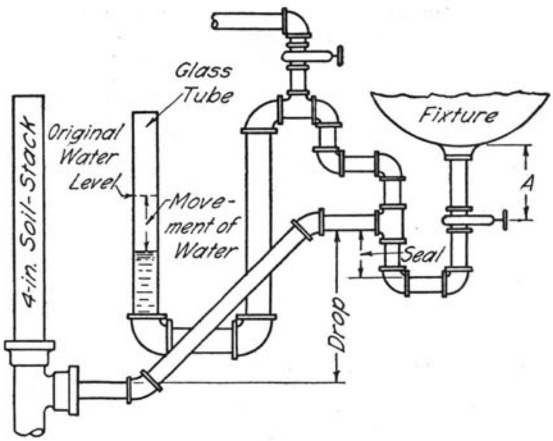


FIG. 29. APPARATUS USED IN SELF-SIPHONAGE TESTS OF VENTED TRAPS

these tests the rates of discharge from the fixture varied between 10 and 45 gallons per minute for about 30 seconds. Vent pipes ¾ in. and 1½ in. in diameter and in lengths up to 6 ft. were used. Summarized or representative values are given in Table 7.

It was concluded from these tests that a crown or continuous vent pipe ¾ in. in diameter will prevent the breaking of the seal of a trap by self-siphonage, provided the drop is not longer than 4 ft. and the rate of discharge is not more than about 18 gallons per minute.

III. A METHOD FOR THE DETERMINATION OF PROPER VENT CAPACITY IN PLUMBING DESIGN

25. *General Conditions.*—From the study of the pressures created in vented traps with various arrangements of piping and rates of discharge it was concluded that a vent pipe having sufficient capacity to prevent the breaking of the seal in a trap by water falling down a soil-stack will have sufficient capacity to prevent the breaking of the seal in the trap under any conditions. Therefore, if vent capacity is provided sufficiently to relieve the pressures resulting from the water falling down the soil-stack, the pressures resulting from any other condition in the plumbing system will be relieved. The study of proper vent capacity was based on the observations of pressure in traps resulting from water falling down the soil-stack.

In formulating a method for the determination of proper vent capacity it has been assumed that the top of the soil-stack will not become closed, the house-drain will not become submerged, no house-trap will be used, and that solid matter will be mixed with the discharge from the water-closets.

26. *Relation Between Maximum and Average Pressures.*—The greater the pressure on a trap the greater the movement of water in the trap. This statement is in accord with the description of pressure as given in Section 6. The greatest or the maximum pressure is, therefore, the pressure to be prevented. In most of the tests so far discussed, the pressures reported represent only the average of a number of observed pressures. It is, therefore, desirable to find a relation between the maximum and the average pressures in order that the maximum pressures may be studied under all the conditions tested. In some tests the maximum and the minimum pressures were observed and the average pressures were computed, and all were recorded as in Tables 9 and 10. From these values and from other values not recorded in these tables, it was found that:

(a) For rates of flow equal to or greater than the simultaneous discharge of two or more water-closets the ratio of maximum pressure, with solid matter present, to the average pressure without solid matter is in no case as great as two.

(b) For rates of flow equal to or less than the discharge from one water-closet falling 42 ft. down a 4-in. soil-stack, the ratio of the maximum pressure, with solid matter present, to the average pressure without solid matter is greater than two, but the maximum pressure, with solid matter present, is only slightly greater than 2 in.

(c) For a rate of flow of 30 gallons per minute falling 42 ft. down a 3-in. soil-stack, the ratio of the maximum pressure with solid matter present to the average pressure without solid matter is about four and a half, and the maximum pressure with solid matter present is 0.33 ft., equal to 4 in.

(d) With solid matter present the ratio of the maximum pressure to the average pressure is in no case greater than two and a half; without solid matter the ratio of the maximum pressure to the average pressure is in no case as great as two.

It is therefore concluded, if traps with a seal 2 in. in depth or more are used, that a vent capacity sufficient to prevent pressures greater

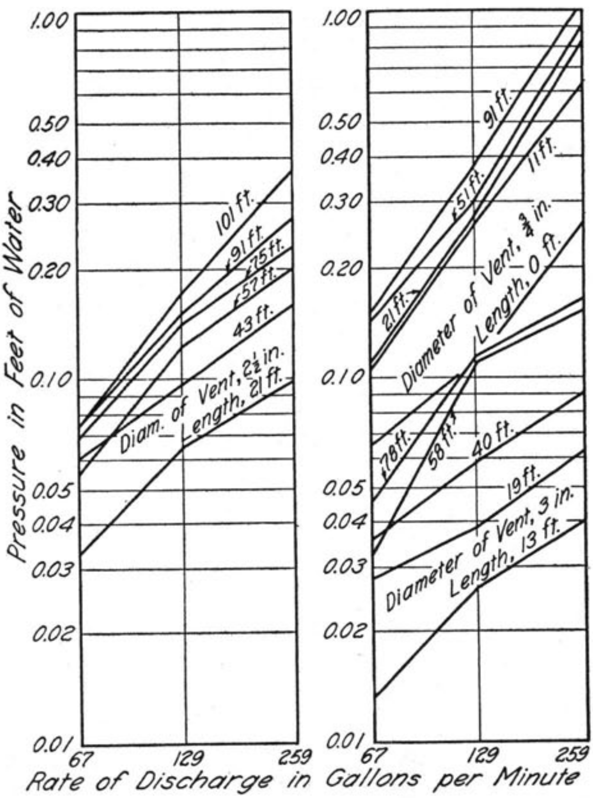


FIG. 30. PRESSURES CREATED IN A PLUMBING SYSTEM AND RATE OF DISCHARGE DOWN THE SOIL-STACK

The traps were vented as noted.

than double the average pressure observed in any series of tests made without solid matter mixed with the discharge will be needed to prevent the breaking of the seal of a trap, with the following exception: When the rate of discharge is below 50 gallons per minute falling more than 30 ft. down a 3-in. soil-stack a vent capacity sufficient to prevent pressures greater than four times the average pressure observed in any series of tests made without solid matter mixed with the discharge will be needed to prevent the breaking of the seal of the trap.

These conclusions with regard to the requisite capacity of vents to prevent excessive pressures caused by solid matter mixed with the discharge are safe because the character of the solid matter used in these

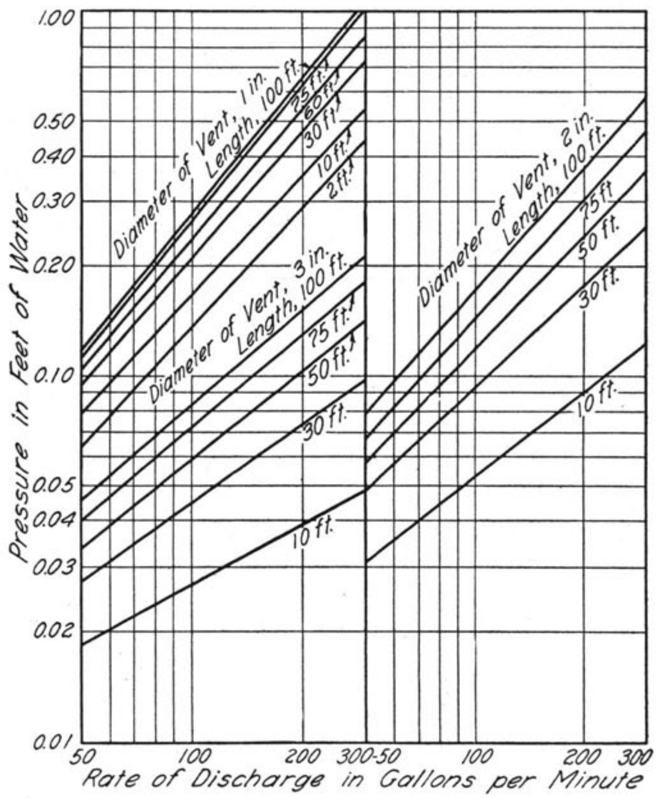


FIG. 31. PRESSURES CREATED IN A PLUMBING SYSTEM AND RATE OF DISCHARGE DOWN THE SOIL-STACK

The traps were vented as noted. The pressures have been derived by the use of the values given in Fig. 30. The soil-stack was 4 inches in diameter and the height of fall of water 42 feet.

tests was such as to create greater pressures than would probably be created by the solid matter ordinarily mixed with the discharges from plumbing fixtures.

27. *Relation between Rate of Discharge and Pressure in a Trap, for Different Vent Capacities.*—The pressures recorded in Table 11 and other pressures observed but not here recorded were plotted as ordinates in Fig. 30 with the corresponding rates of discharge as abscissas. Points for the same length and diameter of vent pipe were connected by a line. The lines thus formed are neither straight nor parallel. As only three

TABLE 16

MAXIMUM POSITIVE PRESSURES WHICH MAY BE CREATED IN CROWN VENTED TRAPS BY WATER FALLING 42 FT. DOWN A 4-IN. SOIL-STACK

The values in this table have been computed by doubling the computed average pressures.

Diameter of Crown Vent inches	Length of Crown Vent feet	Rate of Discharge—gallons per minute						
		30	50	100	150	200	250	300
		Pressure in Feet of Water						
3	10	0.02	0.04	0.05	0.06	0.07	0.08	0.10
3	30	0.03	0.05	0.08	0.10	0.14	0.18	0.20
3	50	0.04	0.06	0.12	0.16	0.20	0.24	0.28
3	75	0.05	0.07	0.14	0.20	0.26	0.32	0.38
3	100	0.06	0.08	0.16	0.24	0.30	0.36	0.42
2½	10	0.03	0.04	0.08	0.12	0.16	0.18	0.22
2½	30	0.04	0.07	0.14	0.22	0.28	0.36	0.42
2½	50	0.05	0.08	0.18	0.28	0.38	0.48	0.56
2½	75	0.06	0.11	0.24	0.36	0.50	0.62	0.74
2½	100	0.07	0.12	0.28	0.42	0.56	0.72	0.88
2	10	0.04	0.06	0.10	0.14	0.18	0.22	0.24
2	30	0.05	0.10	0.18	0.28	0.38	0.44	0.52
2	50	0.06	0.12	0.24	0.36	0.50	0.60	0.74
2	75	0.07	0.14	0.30	0.44	0.60	0.78	0.96
2	100	0.08	0.16	0.34	0.52	0.70	0.96	1.06
1½	10	0.06	0.08	0.16	0.12	0.34	0.38	0.46
1½	30	0.07	0.12	0.26	0.38	0.50	0.64	0.76
1½	50	0.08	0.14	0.30	0.46	0.64	0.80	0.96
1½	75	0.09	0.16	0.36	0.56	0.76	0.96	1.18
1½	100	0.10	0.18	0.40	0.64	0.86	1.10	1.34
1	10	0.09	0.16	0.34	0.52	0.70	0.90	1.08
1	30	0.10	0.18	0.42	0.66	0.92	1.18	1.46
1	50	0.11	0.20	0.46	0.76	1.06	1.36	1.70
1	75	0.12	0.22	0.52	0.84	1.20	1.58	1.98
1	100	0.13	0.24	0.54	0.90	1.30	1.70	2.06
¾	10	0.10	0.20	0.42	0.68	0.94	1.20	1.48
¾	30	0.14	0.26	0.58	0.94	1.30	1.70	2.10
¾	50	0.16	0.30	0.68	1.10	1.54	2.00	2.48
¾	75	0.18	0.34	0.76	1.24	1.74	2.24	2.84
¾	100	0.20	0.36	0.82	1.34	1.90	2.48	3.10

points were available for each line and the pressure readings are accurate only to .05 ft. the degree of accuracy of the location of the lines is not high. So many lines were drawn, however, that the general tendency of their direction could be determined and conclusions could be drawn as to the relation between discharge and pressure for any particular vent. These conclusions have been used in computing the probable maximum pressure in vented traps.

28. *Computation of Probable Maximum Positive Pressure in Vented Traps.*—A second diagram, Fig. 31, similar to Fig. 30, was drawn except that the lines were made straight. The lines were straightened by plot-

TABLE 17

MAXIMUM POSITIVE PRESSURES WHICH MAY BE CREATED IN CROWN VENTED TRAPS BY WATER FALLING 42 FT. DOWN A 3-IN. SOIL-STACK

The values in this table have been computed by doubling the computed average pressures.

Diameter of Crown Vent inches	Length of Crown Vent feet	Rate of Discharge—gallons per minute				
		30	60	90	120	150
		Pressures in Feet of Water				
2	10	0.03	0.04	0.06	0.08	0.10
2	30	0.05	0.08	0.12	0.16	0.18
2	50	0.06	0.12	0.16	0.22	0.26
1½	10	0.04	0.06	0.08	0.10	0.12
1½	30	0.06	0.12	0.16	0.20	0.26
1½	50	0.08	0.14	0.22	0.30	0.38
1	10	0.08	0.20	0.34	0.48	0.60
1	30	0.11	0.30	0.52	0.76	0.94
1	50	0.12	0.34	0.62	0.92	1.16
¾	10	0.10	0.24	0.38	0.56	0.74
¾	30	0.12	0.30	0.54	0.78	1.06
¾	50	0.14	0.36	0.64	0.96	1.32
No Vent		0.16	0.50	1.10	2.5	3.80

ting on logarithmic cross-section paper a series of points for each length and diameter of vent pipe. The abscissas of these points were rates of discharge and the ordinates were corresponding pressures. Straight lines were drawn approximately through these points, and lines such as those in Fig. 31 were produced. The slope and position of such lines were not always consistent, however. These were made consistent by the following process: First, points were plotted on logarithmic cross-section paper for each rate of discharge and diameter of vent pipe, the abscissas of which were the length of the vent pipe and the ordinates the corresponding pressures; secondly, straight lines were drawn approximately through these points; and finally, the position and slope of the original lines were changed to be consistent with the new lines, and these new lines are shown in Fig. 31. The plotting of the points on logarithmic cross-section paper and the drawing of straight lines through these points is consistent with the tendencies of the pressures and rates of discharge observed in the tests, as shown by Figs. 8, 9, 10, and 12. The values in Table 16, and similar tables, were computed from Fig. 31 by doubling the pressures indicated by lines in the figure, in order that the maximum pressures to be expected might be recorded in accordance with the conclusions in Section 26.

TABLE 18

FACTORS BY WHICH THE PRESSURES IN TABLES 16 AND 17 MUST BE MULTIPLIED TO FIND THE PRESSURES FOR OTHER HEIGHTS OF FALL IN A SOIL-STACK ABOVE THE POINT WHERE THE PRESSURE IS TO BE MEASURED

Height of Fall feet	Factor
40	0.88
35	0.63
30	0.43
25	0.27
20	0.16
15	0.076
10	0.028

The values in Table 16 indicate the maximum positive pressures which may be expected in traps with water alone falling 42 ft. down a 4-in. soil-stack. The figures in Table 17 indicate the maximum positive pressures which may be expected in traps with water alone falling 42 ft. down a 3-in. soil-stack. In order that the positive pressures created by water falling a shorter distance down a soil-stack might be computed, Table 18 was prepared. This shows the factors by which the figures in Tables 16 and 17 must be multiplied for other heights of fall in the soil-stack. The factors in Table 18 were computed from the relation that the pressures vary as the five-halves power of the height of fall down the soil-stack.

29. *A Method for the Determination of Proper Vent Capacity in Plumbing Design.*—In designing plumbing equipment so as to avoid excessive pressures in traps the designer will know the maximum rate of discharge down the soil-stack, the height of fall of water from the highest inlet to the base of the soil-stack, the depth of seal in the trap, the type of vent, and either the diameter or the length of the vent pipe. If the length of vent pipe is known, it remains to determine the diameter; if the diameter is known, it remains to determine the greatest length which may be used.

To find the maximum length of vent pipe which may be used to prevent the breaking of a 2-in. seal in a trap connected to the base of the soil-stack proceed as follows:

(1) Consult Table 18 and find the factor corresponding to the greatest height of fall of water in the soil-stack for which the design is being made.

(2) Divide the assumed depth of seal by this factor.

(3) Consult Table 16 or 17 in the group of values corresponding to the diameter of vent pipe fixed by the designer and in the column corresponding to the maximum rate of discharge fixed by the designer find the value computed in the second step. The line of the table in which this pressure is found will give the maximum length of vent pipe which may be used.

For example, let it be assumed that the maximum rate of discharge in a plumbing system may be equivalent to three water-closets discharging simultaneously 150 gallons per minute, and it is desired to determine the permissible length of $\frac{3}{4}$-in. crown vent pipe to use on a trap in the basement which discharges into a 4-in. soil-stack 20 ft. below the point of entrance of the discharge from the highest horizontal waste pipe connected to the soil-stack, so that a trap with a 2-in. (0.17 ft.) seal can be used. The procedure will be as follows:

(1) In Table 18 the factor for 20 ft. is found to be 0.16. Divide 0.17, the depth of seal, by 0.16. The quotient is 1.06.

(2) Consult Table 16 in the group of values corresponding to $\frac{3}{4}$-in. vent pipe. In the column headed 150 gallons per minute the value of 1.06 is seen to lie between 0.94 and 1.10, which allows a maximum length of vent pipe of about 45 ft.

It is to be noted that the size of the vent selected was based on the maximum positive pressure in the soil-stack. In all of the tests made it was found that the greatest positive pressure was always larger than the greatest negative pressure anywhere in the soil-stack. Since a vent is equally effective in relieving either a positive or a negative pressure, if the size of vent determined for relieving the maximum positive pressure is used on traps throughout the plumbing system, the breaking of seals of all traps by either positive or negative pressure will be prevented.

30. *The Vent Capacity Required in a Residence with One Bath Room.*—It will be assumed that the type of residence under consideration will contain a single bath room on the second floor, together with the ordinary number of bath room, kitchen, and laundry fixtures. The greatest height of fall of water in the soil-stack will be assumed as 20 ft., and it will be assumed that a 3-in. soil-stack is to be used.

In this case let it be assumed that the smallest depth of seal in any trap is to be 2 in., that is, 0.17 ft., and that it is required to find the greatest length of $\frac{3}{4}$-in. vent pipe which may be used. Since the maximum height of fall of water in the soil-stack may be 20 ft., the factor in Table 18, as before, is 0.16 and the maximum permissible pressure in Table 16 would be 1.06 ft., but since the rate of discharge is low and a 3-in. soil-stack is to be used, in accordance with conclusion (c) in Section 26, the permissible maximum pressure should be only one-half of this or 0.53 ft. (The pressure actually observed with a fall of 42 ft. in a 3-in. soil-stack was 0.33 ft.) Consulting Table 17, in the group of values corresponding to ¾-in. vent pipe, in the column headed 60 gallons per minute, which is slightly greater than the maximum rate of discharge from one water-closet, it is found that even more than 50 ft. of ¾-in. vent pipe may be used. Dropping down to the next line in the table it is seen that even without the use of a vent pipe the maximum permissible change of the water level in the trap will not be exceeded. It is thus evident that, under the conditions assumed, no vent pipe is needed. If no vent pipe is used, however, it is possible that the trap may siphon itself, and therefore a vent may be necessary to prevent the destruction of the seal by self-siphonage.

31. *Conditions Suitable for the Use of a 3-in. Soil-Stack and No Vent.*—In the conditions given in the preceding example it is evident that a 3-in. soil-stack can be used and that no vent pipes are necessary, except to prevent the destruction of the seal by self-siphonage.

It can be stated in general terms, therefore, that if proper precautions are taken to prevent the destruction of the seal of a trap by self-siphonage, the submergence of the outlet to the house-drain, the stoppage of the top of the soil-stack, and also to prevent the pressures created by the discharge of traps into a horizontal waste pipe from breaking the seal in other traps connected to the same waste pipe, it is reasonably safe to use unvented traps, of any style, with a 2-in. depth of seal, in one-story or two-story residences containing a single bath room and the normal number of kitchen and laundry fixtures connected to one 3-in. soil-stack.

IV. Conclusions

32. *Conclusions.*—The conclusions are listed in the order in which the tests have been reported. In drawing conclusions it has been assumed that vent pipes and connections are wholly open and free from obstruction and that the design of the plumbing system is such that partial or complete closure through the lodgment of grease or other materials is improbable.

(1) The maximum change of level of the water in a trap, resulting from the application of pressure, is approximately the same for all diameters of traps, provided the trap is sufficiently large to render negligible the effect of friction in retarding the movement of the water. The minimum diameter of trap to satisfy this condition seems to be about one inch. Above this size the diameter does not appreciably affect the change of level of the water and, therefore, does not affect the pressures read.

(2) For practical purposes in plumbing design the change of level of the water in traps will be the same under the same applications of pressure, regardless of the depth of water in the trap. Therefore, the depth of water in the trap will not affect the pressures read.

(3) The withdrawal of water from a trap will not weaken its resistance to the passage of air through it, provided the volume of water remaining in the trap is sufficient to fill the connection between the two legs of the trap, and to form a vertical column of a height equal to the depth of seal in that leg of the trap in which the water rises. This conclusion has no bearing on the strength of trap seals to resist self-siphonage.

(4) The resistance of a trap to the passage of air through it (breaking of the seal) varies directly with the depth of the seal.

(5) For safety in plumbing design it should be assumed that a water-closet, other than the automatic valve type which was not tested, may discharge at the rate of 50 gallons per minute for 7 seconds. This is equivalent to a total discharge of about 6 gallons. Ordinarily a water-closet will discharge a smaller amount at a slower rate.

(6) With unvented traps the pressure P varies as the five-halves power of the rate of discharge Q down the soil-stack. The relation can be expressed as $P = KQ^{5/2}$.

(7) With vented traps the pressure P varies as some constant power of the rate of discharge Q. The relation can be expressed as $P = KQ^m$. The value of m is dependent on the type and capacity of the vent. The values of m vary between about one-third for very complete venting such as might be provided by fully opening the crown of the trap and five-halves for no vent.

(8) The positive pressure in unvented traps varies as the five-halves power of the height of fall of water to the point of observation. Neither positive nor negative pressures will be produced

above the point of entrance of water to the soil-stack. The negative pressure is dependent both on the vertical distance the water falls to the point where the negative pressure is measured and on the vertical fall below this point. The greatest positive pressure is greater than the greatest negative pressure anywhere in the soil-stack.

(9) The maximum rate at which water will flow down a 4-in. soil-stack without creating uncontrollable pressures in a plumbing system is high. A 4-in. soil-stack will probably take all of the water that would be delivered to it in a five-story building, a 3-in. soil-stack will probably take all of the water that would be delivered to it in a three-story residence, and a 2-in. pipe is unsuitable to be used as a soil-stack.

(10) The rate at which one horizontal waste pipe of the same diameter as the soil-stack will discharge water into a soil-stack through a sanitary T without backing up in the waste pipe may be taken to be as follows: 2-in. soil-stack, 25 gallons per minute for 7 seconds; 3-in. soil-stack, 50 gallons per minute for 7 seconds; and 4-in. soil-stack, 100 gallons per minute for 7 seconds.

(11) The submergence of the house-drain results in a material increase in the pressures created in a plumbing system. This submergence should be avoided in design when possible, but where unavoidable, the venting of the house-drain or the house-sewer at a point above the highest level of water backing up in the house-drain or the house-sewer will give relief.

(12) The effect of the length of the house-drain on the pressures in a plumbing system need not be considered in plumbing design.

(13) If a house-trap, either vented or unvented, is used at the end of the house-drain the pressures throughout the plumbing system are increased. It is, therefore, concluded that a house-trap should not be used in a plumbing system.

(14) The closure of the top of the soil-stack or the closure of vent pipes will result in such increases in pressure as to endanger the seals in traps. Soil-stacks and vent pipes should, therefore, be designed to prevent the possibility of becoming stopped up. This is in accord with good practice in plumbing design.

(15) The length of a 4-in. connection between a trap and the soil-stack does not affect the pressure on the trap caused by water falling down the soil-stack for traps not more than 25 ft. from the soil-stack. No tests were made on traps at a greater distance from the soil-stack.

(16) The conclusions with regard to the factors affecting self-siphonage are summarized in Section 22.

(17) Continuous or crown venting and loop venting are equally effective in relieving the pressures created in traps by water falling down the soil-stack.

(18) Conclusions with regard to the pressures created in traps by the discharge of fixtures connected to the same horizontal waste pipe and with regard to the efficacy of different types of venting are given in Section 24.

(19) The pressures in vented and unvented traps under different conditions are summarized in Tables 7, 9, 10, 11, 14, and 15.

(20) It is reasonably safe to use unvented traps, of any style, with a 2-in. depth of seal in one-story or two-story residences containing a single bath room and the normal number of kitchen and laundry fixtures connected to one 3-in. soil-stack if precautions are taken as listed on page 74.

APPENDIX

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