Self-Siphonage of Fixture Traps

United States Department of Commerce
National Bureau of Standards
Building Materials and Structures Report 126

BUILDING MATERIALS AND STRUCTURES REPORTS

On request, the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will place your name on a special mailing list to receive notices of new reports in this series as soon as they are issued. There will be no charge for receiving such notices.

An alternative method is to deposit with the Superintendent of Documents the sum of $5, with the request that the reports be sent to you as soon as issued, and that the cost thereof be charged against your deposit. This will provide for the mailing of the publications without delay. You will be notified when the amount of your deposit has become exhausted.

If 100 copies or more of any report are ordered at one time, a discount of 25 percent is allowed. Send all orders and remittances to the *Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.*

The following publications in this series are available by purchase from the Superintendent of Documents at the prices indicated:

BMS1	Research on Building Materials and Structures for Use in Low-Cost Housing	*
BMS2	Methods of Determining the Structural Properties of Low-Cost House Constructions	10¢
BMS3	Suitability of Fiber Insulating Lath as a Plaster Base	15¢
BMS4	Accelerated Aging of Fiber Building Boards	10¢
BMS5	Structural Properties of Six Masonry Wall Constructions	15¢
BMS6	Survey of Roofing Materials in the Southeastern States	15¢
BMS7	Water Permeability of Masonry Walls	*
BMS8	Methods of Investigation of Surface Treatment for Corrosion Protection of Steel	15¢
BMS9	Structural Properties of the Insulated Steel Construction Co.'s "Frameless-Steel" Constructions for Walls, Partitions, Floors, and Roofs	10¢
BMS10	Structural Properties of One of the "Keystone Beam Steel Floor" Constructions Sponsored by the H. H. Robertson Co	10¢
BMS11	Structural Properties of the Curren Fabrihome Corporation's "Fabrihome" Constructions for Walls and Partitions	10¢
BMS12	Structural Properties of "Steelox" Constructions for Walls, Partitions, Floors, and Roofs Sponsored by Steel Buildings, Inc	15¢
BMS13	Properties of Some Fiber Building Boards of Current Manufacture	10¢
BMS14	Indentation and Recovery of Low-Cost Floor Coverings	10¢
BMS15	Structural Properties of "Wheeling Long-Span Steel Floor" Construction Sponsored by the Wheeling Corrugating Co	10¢
BMS16	Structural Properties of a "Tilecrete" Floor Construction Sponsored by Tilecrete Floors, Inc	10¢
BMS17	Sound Insulation of Wall and Floor Constructions	20¢
Supplement to BMS17, Sound Insulation of Wall and Floor Constructions		5¢
Supplement No. 2 to BMS17, Sound Insulation of Wall and Floor Constructions		15¢
BMS18	Structural Properties of "Pre-fab" Constructions for Walls, Partitions, and Floors Sponsored by the Harnischfeger Corporation	10¢
BMS19	Preparation and Revision of Building Codes	†
BMS20	Structural Properties of "Twachtman" Constructions for Walls and Floors Sponsored by Connecticut Pre-Cast Buildings Corporation	10¢
BMS21	Structural Properties of a Concrete-Block Cavity-Wall Construction Sponsored by the National Concrete Masonry Association	10¢
BMS22	Structural Properties of "Dun-Ti-Stone" Wall Construction Sponsored by the W. E. Dunn Manufacturing Co	10¢
BMS23	Structural Properties of a Brick Cavity-Wall Construction Sponsored by the Brick Manufacturers Association of New York, Inc	10¢
BMS24	Structural Properties of a Reinforced-Brick Wall Construction and a Brick-Tile Cavity-Wall Construction Sponsored by the Structural Clay Products Institute	15¢
BMS25	Structural Properties of Conventional Wood-Frame Constructions for Walls, Partitions, Floors, and Roofs	20¢
BMS26	Structural Properties of "Nelson Pre-Cast Concrete Foundation" Wall Construction Sponsored by the Nelson Cement Stone Co., Inc	10¢
BMS27	Structural Properties of "Bender Steel Home" Wall Construction Sponsored by the Bender Body Co	10¢
BMS28	Backflow Prevention in Over-Rim Water Supplies	15¢
BMS29	Survey of Roofing Materials in the Northeastern States	20¢
BMS30	Structural Properties of a Wood-Frame Wall Construction Sponsored by the Douglas Fir Plywood Association	15¢
BMS31	Structural Properties of "Insulite" Wall and "Insulite" Partition Constructions Sponsored by The Insulite Co	25¢

*Out of print.
†Superseded by BMS116.

[List continued on cover page III]

UNITED STATES DEPARTMENT OF COMMERCE • Charles Sawyer, *Secretary*
NATIONAL BUREAU OF STANDARDS • E. U. Condon, *Director*

Self-Siphonage of Fixture Traps

John L. French and Herbert N. Eaton

Building Materials and Structures Report 126

Issued October 15, 1951

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 20 cents

Foreword

This report on the self-siphonage of plumbing fixture traps is the last of a series of three reports giving the results of an investigation of the problems involved in the proper venting of single plumbing fixtures or relatively small groups of such fixtures in dwellings. The first report, BMS118, Stack venting of plumbing fixtures, was published in January 1950; and the second is BMS119, Wet venting of plumbing fixtures, issued in December 1950. The investigation, the results of which are presented in these three reports, was first undertaken for the National Housing Agency in connection with the Veterans Emergency Housing Program of that Agency and was continued and completed under the Housing Research Program of the Office of the Administrator, Housing and Home Finance Agency, as part of the research program of that Agency under its statutory authority.

Self-siphonage is the reduction in the water seal of a fixture trap by the discharge from the fixture to which the trap is connected. The purpose of the trap is to interpose between the sewer and the interior of the building a water seal that will prevent sewer air from passing back into the building and causing offensive odors there. This water seal is normally from 2 to 4 inches in depth and is sufficient to prevent the passage of sewer air into the building under any ordinary conditions. However, if, through self-siphonage or any other cause, part of the water seal in the trap is lost, then the pressure fluctuations in the drainage system of the building, which occur as the result of the discharge of the fixtures on the system, may be great enough to bubble sewer air back through the trap seal.

At present it is customary to control self-siphonage by limiting the unvented length of drain connected to the fixture. However, this investigation has shown that other factors than the length of fixture drain affect self-siphonage. Among these are the diameter of the trap and the depth of trap seal, the diameter and slope of the fixture drain, the type of vent fitting used, and the rate of discharge of the fixture. This investigation has shown to what extent these other factors affect trap-seal losses, and the paper gives the necessary information to take them into account properly in the design of the system.

The paper also shows the importance of standardizing fixture traps and the hydraulic characteristics of plumbing fixtures, such as lavatories, sinks, and trays.

E. U. Condon, *Director*.

Contents

Self-Siphonage of Fixture Traps

John L. French and Herbert N. Eaton

This paper describes the methods used and the results obtained in an experimental investigation of the self-siphonage of fixture traps in plumbing systems. Self-siphonage is the reduction in depth of the water seal in the trap by flow from the fixture that discharges through the trap. The different factors that affect self-siphonage are determined, and methods for reducing the ill effects of self-siphonage are suggested. Finally, recommendations and conclusions in a form suitable for use by code-writing authorities are presented.

1. Introduction

The flow of sewer gas from the plumbing drainage system into a dwelling is commonly accepted as being undesirable, and under unusual circumstances poisonous gases might conceivably be introduced into the building in this way. To prevent such occurrences, traps containing a liquid seal are almost universally installed on plumbing fixtures. Under certain circumstances the discharge of a fixture may, after it has ceased, leave the water level in the trap lower than its normal level, which is at the level of the trap weir (see fig. 1). The process whereby a reduction in the level of the trap seal is caused by the discharge of the fixture to which the trap is connected (notably in the case of the lavatory) is commonly known as *self-siphonage*. The phenomenon of self-siphonage should be clearly distinguished from *siphonage*. The latter phenomenon also may reduce the depth of seal in a fixture trap, but in this case the phenomenon is due to the discharge of other fixtures on the system, this discharge resulting in transient local pressure reductions that siphon water out of the trap attached to the fixture in question.

It has long been known that the trap-seal losses caused by self-siphonage are frequently more severe with long unvented lengths of fixture drains than with short ones, and plumbing codes commonly place a limit on the distance between the fixture trap and its protecting vent. However, there has been little uniformity in these code requirements, and the need for an experimental investigation of the self-siphonage of plumbing fixtures that would afford a sound basis for establishing code requirements in this respect has been apparent. For this reason the Housing and Home Finance Agency, at the suggestion of the Uniform Plumbing Code Committee, sponsored a research program at this Bureau which consisted, among other things, of an investigation of the process of self-siphonage. The purpose of this report is to present the results of this investigation.

In analyzing some portions of the experimental data use has been made of the principles of dimensional analysis. This has made it possible to bring order out of a great mass of observational data taken in the course of the investigation and has provided a means of predicting approximately what amount of self-siphonage will occur under conditions not actually tested. This would have been impossible had this mathematical tool not been used. Thus, certain sections of the paper have been written for the engineer, not for the practical plumber. It is believed, nevertheless, that the conclusions resulting from this investigation are stated in sufficiently detailed form to enable the practical man to use them with ease.

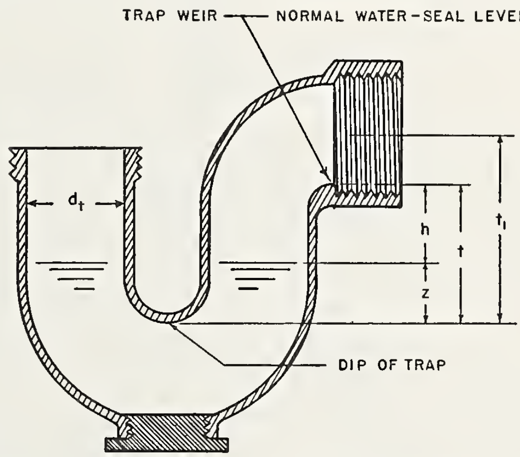

FIGURE 1. *Definition sketch of trap. z=remaining trap seal, h=trap seal loss, and t=depth of trap seal.*

2. Nature of the Phenomenon

The phenomenon of self-siphonage, while very common in plumbing systems, is an extremely complicated flow problem, and hence it does not lend itself to analytical treatment. The only reasonable method of approach seems to be to obtain empirical results by experiment and then to generalize the results as far as possible by theoretical means.

A system typical in all respects of those that are considered in this report is shown in figure 2. The system consists of a lavatory, an outlet orifice, a down pipe, a trap, a fixture drain, and a vent fitting and waste pipe. Just below the outlet orifice there is an overflow opening into the down pipe through which overflow water can discharge or air can aspirate into the down pipe.

When a flat-bottomed or round-bottomed fixture, such as a sink, bathtub, or lavatory discharges its contents, the rate of discharge is relatively high at first, decreasing slowly as the depth of water in the fixture decreases, until suddenly a sharp fall almost down to zero flow occurs. The beginning of this sharp fall is marked by the formation of a vortex, which persists until the fixture is empty, except for the minute flow from the film of water remaining on the surface of the fixture at the end of the discharge. The flow that occurs after the vortex forms is called the *trail discharge.* The final minute flow from the film on the surface of the fixture is called *film flow* or *film discharge.* The sequence of flows described above is illustrated in figure 3, which shows the discharge curve obtained in the laboratory for a bathtub.

When a fixture discharges through a P-trap, such as is shown in figure 1, as the flow nears its end, the inertia of the water moving in the trap tends to carry the water out of the trap into the drain. This effect will be the more pronounced the more abruptly the flow ceases and the greater the rate of flow just prior to its cessation. The result is to decrease the remaining trap seal at the end of the flow.

A second way in which the trap seal may be reduced at the end of the discharge from the fixture is through a reduction in pressure in the drain due to the moving water in the drain filling the cross section of the drain at one or more points and thus producing a pressure reduction upstream toward the trap when the flow from the fixture ceases. This has the effect of pulling the

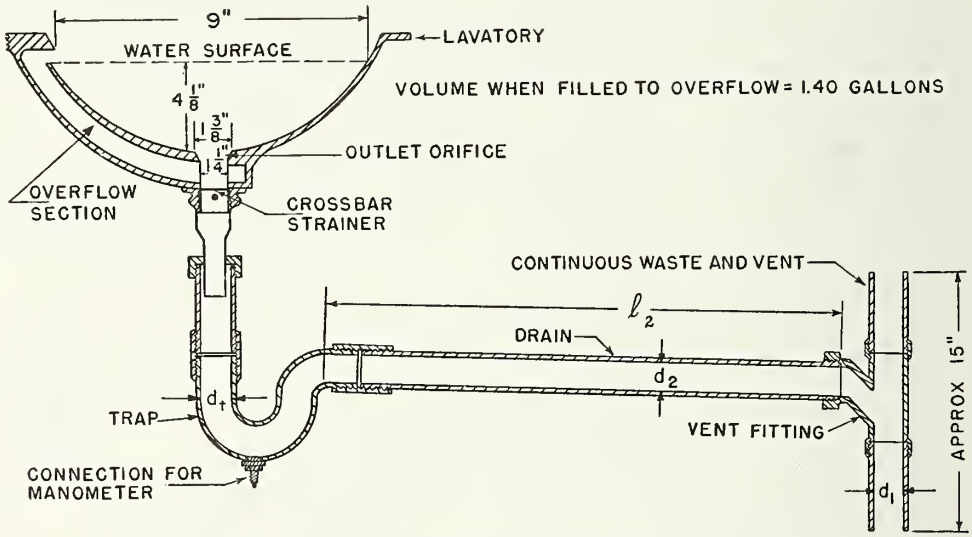

FIGURE 2. *Self-siphonage test system.*

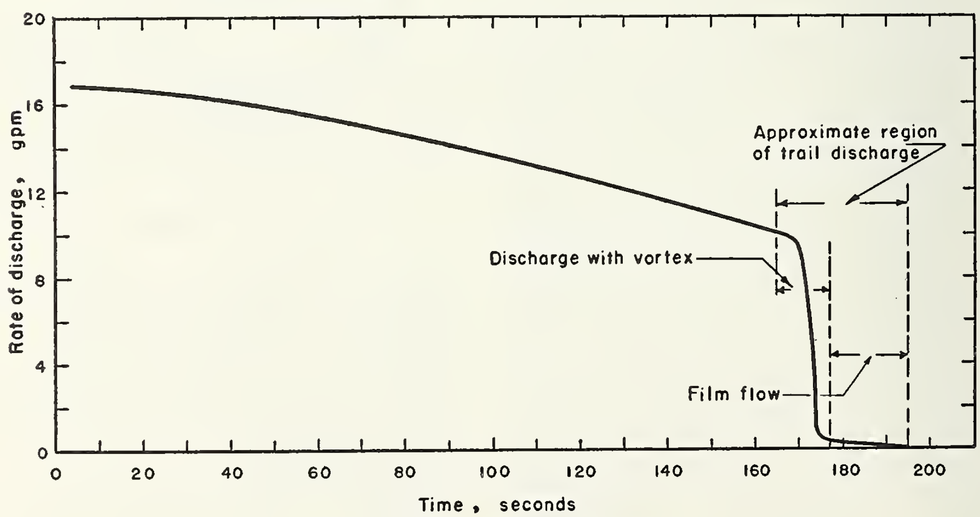

FIGURE 3. *Discharge curve for bathtub.*

water out of the trap and leaving the trap with a reduced seal.

There is still a third way in which trap-seal reductions due to self-siphonage can occur. The water flowing through the trap ordinarily carries with it bubbles of air. This air comes from the fixture that is discharging. First, air is entrained by the water passing the overflow outlet just below the fixture; and second, when the vortex forms in the fixture, air is carried down through this vortex with the flowing water. The air coming from these two sources is carried through the trap in the form of bubbles by the discharge. These bubbles tend to drag the water with them as they pass upward through the outlet leg of the trap and hence constitute another means of reducing the trap seal at the end of the flow.

FIGURE 4. *Effect of trapped air in drain.*

Another way in which air may be drawn through the trap is the following. If the flow from the fixture ends abruptly, the water level in the inlet leg of the trap may be pulled down to the level of the dip of the trap, and air may then pass into the outlet leg of the trap, rising through the water in the form of bubbles. We have obtained motion pictures of this phenomenon occurring in a transparent plastic trap.

However, there are several ways in which a trap-seal reduction due to any of the abovementioned causes may be prevented or may be partly or wholly compensated by refill of the trap. The gradual diminution of flow that occurs in trail and film discharge tends to replenish the trap seal. Secondly, when the flow from the fixture ceases, the cross section of the drain may be completely filled with water along its entire length or at short intervals along its length (see fig. 4), and water tends to slough off the ends of the slugs of water. Some of this water will flow back up the drain, and it is possible that water from the slug furthest upstream may reach the trap and partly or wholly refill it. Again, it has been observed in systems built of transparent plastic material that, at the end of the flow, waves may be reflected from the vent fitting and that, if the drain is sufficiently short and is not laid at too great a slope, these waves will reach and replenish the trap seal.

3. Statement of the Problem

The function of the water seal in fixture traps is, as has already been stated, to prevent sewer gases from entering the dwelling in objectionable amounts, and any reduction in trap seal due to self-siphonage may impair the ability of the trap to perform its function properly. The specific problem of this investigation was to determine the factors that affect self-siphonage and, more particularly, to establish limits on drain lengths, slopes, and diameters, and other pertinent variables that would insure that excessive trap-seal losses due to self-siphonage would not occur.

In this connection, it may be pointed out that the trap-seal losses observed in tests of wet and stack-vented systems under certain conditions are due in part to the self-siphonage process. For example, if a wet-vented fixture is discharged simultaneously with a fixture draining into its wet vent, the resulting seal loss of the wet-vented fixture will be due in part to self-siphonage as defined above. However, the problems of stack venting and wet venting have been treated in earlier papers [1, 2],[1] and in this paper the system will be considered to be backvented.

The terms *remaining trap seal, trap-seal loss,* and *depth of trap seal* will be used frequently in this paper, and for convenience they have been defined in figure 1.

4. Previous Consideration of the Problem

Only a limited amount of data on the self-siphonage of plumbing-fixture traps has been published. Tests on the siphonage of fixture traps were made as early as 1880 [3], but no record of investigations of self-siphonage at such an early date has been found. Perhaps the most systematic investigation of the subject was made by Hunter in 1924 [4]. From tests made with lavatories, Hunter concluded that the diameter of the outlet orifice of the fixture had a marked influence on the amount of self-siphonage that resulted, with the larger outlet orifices yielding the greater trap-seal losses.

Hunter inferred correctly that this effect of the size of outlet was due to its influence on the rate of discharge from the fixture. He also made a few tests on the effect of depth of trap seal on the self-siphonage process, and his test results lead to the conclusion that, while increased depth of seal gave increased trap-seal losses, the remaining depth of seal—which is the important quantity—was also increased. This conclusion agrees with results of the investigation reported in this paper. Hunter's data also indicated that an increase in the slope of the fixture drain from ¼ to ½ inch per foot, or an increase in the length of the fixture drain, caused increased trap-seal losses.

[1] Figures in brackets indicate the literature references at the end of this paper.

Hunter [4, p. 140] concluded from tests on lavatories, kitchen sinks, laundry trays, and bathtubs:

> . . . the following table summarizes the results of the experiments, giving what are believed to be safe maximum lengths for nominally horizontal unvented wastes from fixtures connected to a stack or vented branch at points where they are free from detrimental aspirating or back-pressure effects. It is understood that they refer to self-siphonage only. Possible increase in self-siphonage due to fouling has been taken into account.

Lengths of nominally horizontal unvented waste pipes believed to be safe against self-siphonage

Plain P-traps nominal depth full seal	Safe length of waste pipes for—		
	Wash basin with fall not greater than ½ inch to 1 foot or less than ¼ inch to 1 foot	Wide-bottomed fixtures with fall of—	
		½ inch to 1 foot	¼ inch to 1 foot
Inches	*Feet*	*Feet*	*Feet*
2	4	4	8
3	6	6	12
4	8	8	16

> These lengths are from the center of the trap to stack or larger vented branch waste and would permit one 90° elbow in the waste at a distance not greater than 18 inches from the inlet arm of the trap. Elbows in other positions should be counted as equivalent lengths of pipe.

In this connection, it may be noted that the Subcommittee on Plumbing of the Building Code Committee in their report [4] did not utilize Hunter's results in the form of the above table, but merely limited the unvented length of fixture drain to 5 feet for all fixtures.

Dawson and Kalinske [5] have reported a series of tests on the relative merits as regards self-siphonage of P traps and deep-seal traps, but it was not their purpose to determine permissible unvented lengths of fixture drains, and none were reported.

Babbitt [6, 7] made investigations in 1924 and 1928 of the factors that affect self-siphonage of plumbing fixtures, but his test procedure was not such as to yield any information on permissible unvented lengths of fixture drains.

5. Preliminary Considerations

The analysis of data on trap-seal losses is quite difficult because of the many variables that affect these losses and because of the complicated flow phenomena involved. However, we can predict certain relations that should exist by utilizing the methods of dimensional analysis and available knowledge of the physics of the problem.

5.1. Typical System in Which Self-Siphonage May Occur

A system typical of those which we shall consider in this paper is shown in figure 2. The system consists of a lavatory, an outlet orifice, a down pipe, a trap, a fixture drain, a vent fitting, and a vent and drain pipe. Just below the outlet orifice there is an overflow opening into the down pipe, through which overflow water can discharge or air can aspirate into the down pipe.

When we discuss the flow phenomena in the system, it will be convenient to consider the system in four separate parts: (1) The fixture outlet orifice and down pipe, (2) the trap, (3) the fixture drain, and (4) the vent fitting and waste and vent pipe. It is conceivable that any one of these four parts of the system might be the controlling factor in determining what the flow out of the fixture will be for a given depth of water in the fixture.

If part of the trap seal is removed owing to a pressure reduction in the drain that pulls the water out of the trap or to the inertia of the water column in the trap at the end of the discharge from the fixture, refill can occur in two ways. First, if the fixture has a flat bottom, a substantial amount of *trail discharge* will occur. That is, after the fixture has discharged nearly all of its contents at a relatively high rate of flow, a sudden reduction in the rate of flow will occur, as has been explained earlier in this paper, and the last fraction of an inch of depth of water in the fixture will flow out at a small and gradually diminishing rate. This flow will be too small to decrease the trap seal further as it passes through the trap, and it will likewise be too small to cause pressure reductions in the drain, so that it will tend to refill the trap to its completely full state.

Second, refill may occur from water in the drain if (a) the water level in the drain is higher than the crest of the trap weir, (b) if waves reflected from the vent fitting move back up the drain and overflow the trap weir, and (c) if water sloughs off from the upstream end of a slug of water filling the cross section of the drain and flows back over the crest of the trap weir.

5.2. Action of Trap

The authors have never seen in the literature a detailed discussion of the action of a P-trap, which is the type considered in this paper, so they will next consider this question in some detail. The immediate discussion will relate to the case in which no refill of the trap occurs.

a. No Refill of Trap

Figure 5, A, illustrates the situation that exists when the trap is filled to its normal level; that is, to the level of the crest of the trap weir with the air pressure the same above the water level in both legs of the trap. It is assumed that there is no flow from the fixture to which the trap is attached. Now if pressure fluctuations in the drain lead to a momentary or persisting pressure excess in the drain over the atmospheric pressure existing in the down pipe, then we shall have the situation shown in figure 5, B. The water level will fall in the outlet leg and rise in the inlet leg of the trap until equilibrium has been attained. We have the following relation between the difference in water levels thus produced and the excess pressure in the fixture drain:

$$\Delta p = \rho g \Delta h, \tag{1}$$

where

ρ = the density of the water in the trap,
Δp = the excess pressure in the drain,
g = the acceleration of gravity,
Δh = the difference in water levels in the two legs of the trap.

Now, if the pressures on the two sides of the water seal equalize, there will be no loss from the trap (except possibly a small loss due to the over-

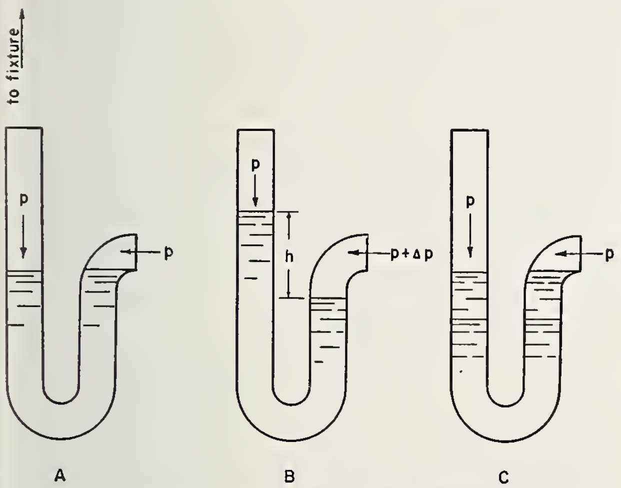

FIGURE 5. *Effect on trap seal of excess pressure in drain.*

shooting of the column of water due to its inertia, particularly if the pressure changes suddenly), see figure 5, C.

In an actual system, however, the pressure in the drain will fluctuate above and below the atmospheric pressure in the down pipe, so that sometimes there will be a pressure reduction in the drain. Under these conditions the water level in the inlet leg of the trap will be pulled down below the level of the trap weir, possibly as far as is shown in figure 6, B, while water will flow out of the outlet leg over the trap weir and will thus be lost. If a succession of such pressure reductions takes place, the losses will, of course, not be additive, but will correspond to the largest pressure reduction that has occurred.

Figure 6, B, shows the condition that exists when the pressure reduction in the drain is just sufficient to pull the water level in the inlet leg of the trap down to the level of the dip of the trap, but obviously the pressure reduction may be only sufficient to pull the water level in the inlet leg down to some intermediate position, or it may be so great that air will be sucked through the water seal at the bottom of the trap. The case shown

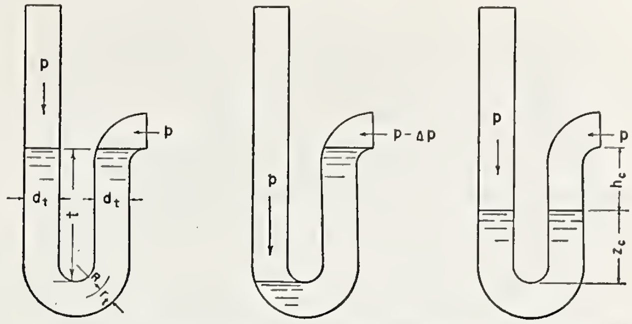

FIGURE 6. *Effect on trap seal of reduced pressure in drain.*

in figure 6, B, is a special one that will receive consideration later in this report.

After a pressure reduction in the drain, when the water levels in the two legs of the trap again equalize, the condition will be as shown in figure 6, C. The magnitude of the loss thus produced, whether it be caused by the discharge of other fixtures or by the discharge of the fixture on this drain (i. e., from self-siphonage), should not be permitted to exceed a certain amount, which may be different for different traps, if we are to prevent the passage of sewer gas in objectionable quantities back through the trap into the building under conditions of fluctuating pressures in the drain. Once a particular trap-seal loss, or a particular remaining depth of trap seal, has become generally accepted as the maximum or minimum that should be permitted, then the system should be designed so that this loss will not be exceeded under any but very infrequently occurring circumstances.

Building drainage systems are ordinarily designed so that pneumatic pressure fluctuations in the fixture drains will not exceed about ± 1 inch head of water. Obviously, if there is a one-half inch depth of water in the trap, measured upward from the dip of the trap, the trap seal will just be adequate to prevent sewer gas from being forced back through the seal into the down pipe and thence into the building when the air pressure in the drain is 1-inch head of water above atmospheric pressure. If the trap seal is reduced so greatly that an air passage exists below the dip of the trap, then gases in the drainage system can pass back freely into the building whenever pressures in excess of atmospheric pressure exist in the drain.

b. Refill of Trap

In the self-siphonage process there are two ways in which the trap seal may be replenished after the discharge of the fixture connected to the trap in question has ceased. These consist of the refill of the trap by the trail discharge of the fixture and the refill of the trap by water flowing back from the fixture drain into the trap.

At first thought, it might seem that the flow taking place through a trap ordinarily consists of

954486—51——2

water only. However, this is not the case, as has already been pointed out. In most instances, air is carried with the water also. We have observed this phenomenon in a transparent trap and fixture drain connected to a lavatory, and these observations indicated that air entered the trap in three ways. First, air was entrained by the water as it passed the overflow outlet just below the lavatory, and this air was carried through the trap in the form of bubbles.

Second, as the water surface in the lavatory continued to recede, a vortex formed in the lavatory, and in this way additional air was carried through the trap into the drain with the water.

Third, near the end of the discharge of the lavatory, with its attendant rapid decrease in the rate of flow through the lavatory outlet orifice, water was flowing out of the trap more rapidly than it entered, owing primarily to the inertia of the water in the trap and drain. Hence the water surface in the inlet leg of the trap receded to such an extent that in many instances air bubbled past the dip of the trap and entered the outlet leg of the trap. This latter manner in which air enters or passes through a trap is especially noticeable when a large pressure reduction occurs in the fixture drain near the end of the discharge period.

Now if the rate of flow in the drain and the diameter of the drain are not sufficient to close off the passageway in the inlet branch of the stack fitting, this air can pass off to the vent or stack and exerts no particular effect on the nature of the flow in the drain.

However, if the flow is sufficiently great to close off the passageway just referred to, then the air in the drain becomes trapped between the solid mass of water in the vent fitting and the water in the trap and causes changes in the nature of the flow in the drain. This in turn affects the pressures in the drain and hence on the outlet end of the trap when the discharge from the fixture ceases.

The following is typical of the phenomena that were observed when air entered the drain in the first manner described above. The entrained air from the overflow outlet entered the drain in the form of bubbles, which rose to the top of the drain at some indefinite point along it. If the quantity of air that collected in this way was sufficiently large, the drain, which was flowing full from the trap weir to this point, flowed only partly full from this point on to the vent fitting. As the volume of entrained air diminished near the end of the lavatory discharge, the water frequently rose to the top of the drain along one or more portions of its length, filling the entire cross section of the drain (see fig. 4). Thus one or more plugs of water formed in the drain near the end of the period of discharge from the lavatory.

As the flow from the lavatory trailed off, the velocity of these plugs of water toward the vent fitting decreased, owing to the adverse head of water in the trap, which tended to slow them down; and at the same time the lengths of the plugs of water diminished, owing to the sloughing off of water at their upstream and downstream ends. If one of these plugs was sufficiently near the trap when this sloughing off occurred, some of the water that sloughed off from the upstream end of the plug flowed backward up the drain and partly or entirely refilled the trap. When the plug was further down the drain, this temporary backflow of water in the drain did not reach the trap, and hence no refill from this cause occurred.

Under test conditions that were as nearly alike as it was possible to make them, the plugs of water that formed as described above varied greatly in size and location, and hence their effect on the remaining trap seal varied greatly. Thus it is apparent that there is no single definite flow condition in the drain corresponding to the discharge of the lavatory, so that considerable variation in trap-seal loss must be expected, even when the conditions are as nearly alike as it is possible to make them.

It was observed also, when the fixture drain was short, that refill entered the trap from the drain because of waves reflected from the vent fitting.

Another way in which partial or complete refill of a trap can occur is encountered when a bathtub trap and drain connect to a wet vent. This phenomenon has been described elsewhere [2] and will not be discussed here.

With regard to the refill of the trap by trail discharge, it is well known that with fixtures having relatively flat bottoms, such as a sink, a laundry tray, or a bathtub, the trail discharge lasts longer and the film discharge is more pronounced than it is with a round-bottomed fixture, such as a lavatory, and hence there is a greater tendency in the former case for refill of the trap to occur.

The characteristics of the discharge curve for a bathtub—a flat-bottomed fixture—are shown in figure 3. The tub had initially a 10-inch depth of water in it. As the water surface lowered, the rate of flow gradually fell off, until suddenly a sharp fall almost down to zero occurred. The beginning of this sharp fall is marked by the formation of a vortex that persists until the tub is empty, except for the minute rate of flow from the film of water remaining on the surface of the tub at the end of the discharge.

5.3. Trap-Seal Loss

There are various ways of expressing the "trap-seal loss" or the "limiting trap-seal loss." By "limiting trap-seal loss" we mean that trap-seal loss that is arbitrarily selected by general agreement as being the maximum that can be permitted if we are to have assurance that sewer air will not pass through the trap seal back into the interior of the building.

If we are analyzing the problem from the standpoint of dimensional analysis, we should naturally express this loss as the ratio of the trap-seal loss, h, to the original depth of water in the trap (measured from the dip of the trap) that is, as h/t.

It is common practice in plumbing codes to restrict the depth of trap seal, t, to values between 2 and 4 inches, and traps are made with different values of t. For example, the traps used in this investigation had the dimensions given in table 1.

TABLE 1. *Dimensions of traps used in this investigation*

Trap	t	d_t	t/d_t	See figure—
	Inches	*Inches*		
1¼-inch adjustable cast brass	2.00	1.188	1.68	7
1¼-inch drawn brass tubing	3.188	1.125	2.83	8
1¼-inch cast brass	1.75	1.25	1.40	9
1½-inch drawn brass tubing	3.563	1.375	2.59	10
1½-inch cast brass	2.25	1.50	1.50	11

Obviously, the value of h/t may vary from zero to unity. When this ratio has reached the value zero, it denotes zero trap-seal loss. When it has reached the value unity, this means that the water has been removed from both legs of the trap down to the dip of the trap and that minute changes of pressure in the proper direction will suffice to force sewer gas into the building. One investigator [4, p. 137] has proposed that a value of 1/2 be used as the value of h/t to constitute the dividing line between satisfactory and unsatisfactory performance of the trap.

However, there are two other common methods of establishing the limiting trap-seal loss, either of which has a more practical significance than the one just discussed. The first is to base the limiting trap-seal loss on a fixed remaining depth of trap seal. This is probably the most logical criterion to use, since the ability of the trap to prevent the passage of sewer gas back into the building depends on the remaining trap seal. A value of 1 inch for this limiting value of the trap seal is quite commonly used.

The other method of establishing the limiting trap-seal loss is to define it as a fixed reduction in trap seal, regardless of the initial depth of seal. This is a simple and safe definition to use and has other advantages, but for large depths of trap seal it is excessively safe and is not as logical as the definition given in the preceding paragraph.

A fourth method of defining the limiting trap-seal loss is offered here for the first time, as far as the authors know, see figure 6. Figure 6, A, shows the conditions in the trap when the trap-seal level is at the crest of the trap weir. This is the normal initial condition. Now assume that a pressure reduction in the drain or other condition causes the water level in the inlet leg to fall until it just reaches the dip of the trap as shown in figure 6, B. The water thus displaced flows over the trap weir and down the drain, and thus is not available to refill the trap when the pressures on the two sides of the trap seal equalize. Now assume that the pressures do equalize, and the levels in the two legs again are the same. This condition is shown in figure 6, C. We propose the name, "critical trap-seal loss," for this condition.

The critical trap-seal loss is the maximum loss that can occur in the trap, unless the pressure reduction in the drain becomes and remains for an appreciable length of time so excessive that air is sucked from the inlet leg of the trap through the water seal into the drain, and in this process carries with it some of the water in the trap by what may be called a pumping process.

Thus the critical trap-seal loss corresponds to a natural maximum loss that can occur for any P-trap and hence suggests itself as a natural criterion to adopt. However, the occurrence of the critical trap-seal loss for a particular trap might conceivably result in a remaining trap seal of less than 1 inch, which fact has a real significance if we design the system so that the pressure reductions in the drain do not exceed 2 inches. Thus, if this critical trap-seal loss were adopted as the borderline between satisfactory and unsatisfactory performance, we would have to examine the dimensions of each trap used to see whether the critical trap-seal loss for that particular trap would leave a remaining trap seal of less than 1 inch. This question is discussed in section 5.5.

5.4. Comparison of Critical Trap-Seal Loss With 1-Inch Trap-Seal Reduction and 1-Inch Remaining Trap Seal

The traps investigated are shown in figures 7, 8, 9, 10, and 11. Because of the desirability of making certain simplifications in the computations, these traps will be divided into two groups. The first group includes the 1¼-inch adjustable cast-brass trap shown in figure 7, the 1¼-inch drawn-brass-tubing trap shown in figure 8, the 1¼-inch cast-brass trap shown in figure 9, and the 1½-inch drawn-brass-tubing trap shown in figure 10. The other trap, the 1½-inch cast-brass trap shown in figure 11, will be considered in another manner.

The basis for dividing these traps into the above groups is: with the first group of four traps, the radius of curvature of the U-bend is nearly the same as the radius of the outlet bend. By making the assumption that these two radii are equal, a considerable simplification in the computations results, as will appear in the analysis to be given. The fifth trap, which is considered separately, has a very small radius of curvature of the outlet bend and a fairly large radius of curvature for the U-bend. It will be assumed in the computations relating to this trap that the outlet leg is cylindrical from the downstream end of the U-bend to the level of the trap weir. It then becomes necessary to compute the volume of water in the U-bend of the trap from the upstream end of the U-bend to the level of the dip of the trap. This is a somewhat tedious process.

The following applies to the four traps shown in figures 7 to 10, inclusive, see figure 12:

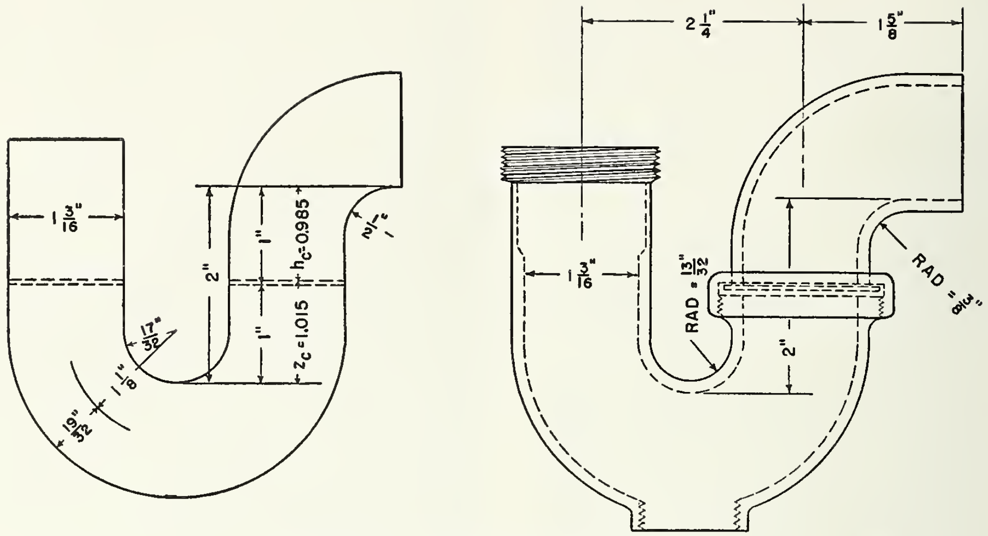

FIGURE 7. *1¼-inch adjustable brass trap.*

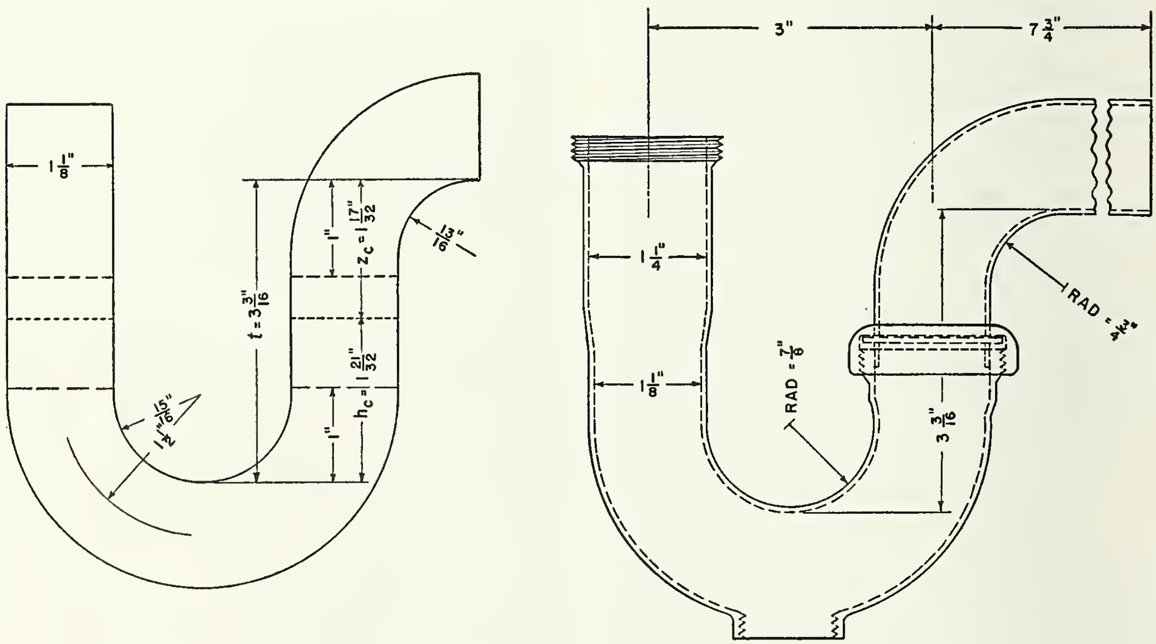

FIGURE 8. *1¼-inch drawn-brass-tubing trap.*

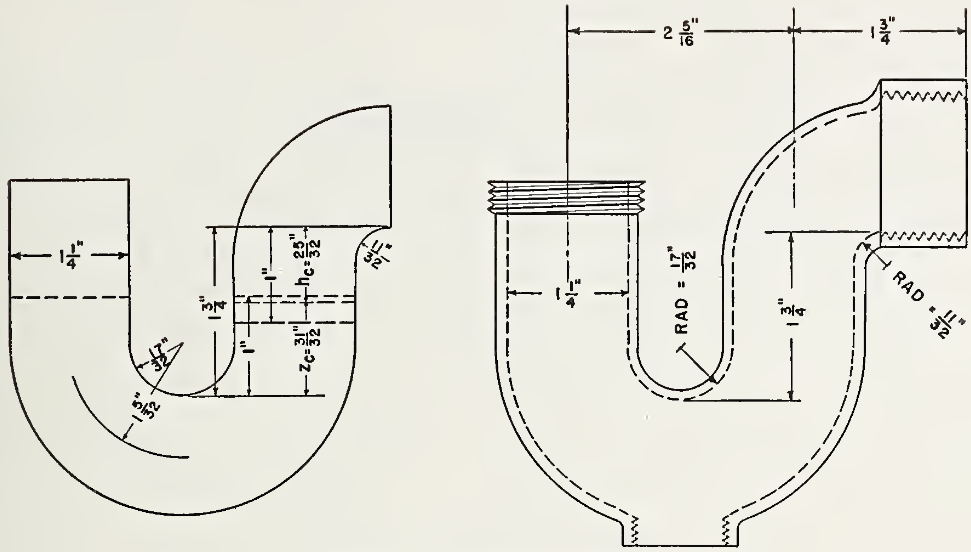

FIGURE 9. *1¼-inch cast-brass trap.*

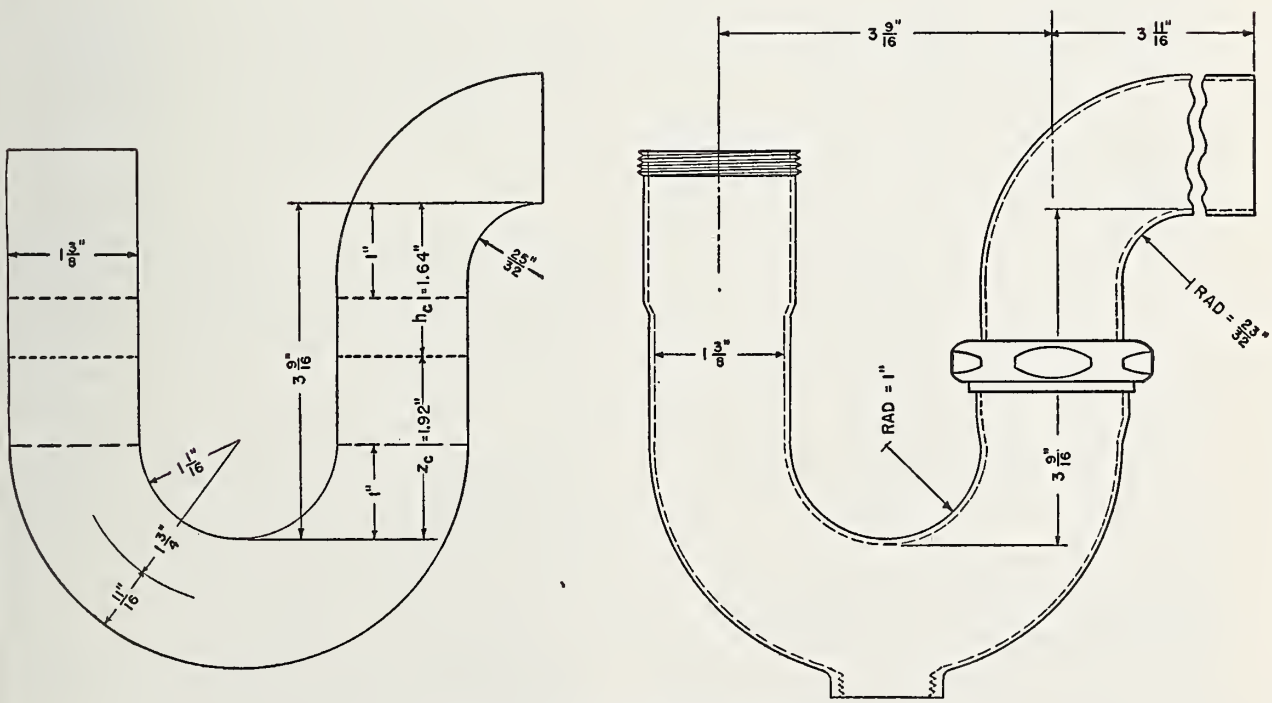

FIGURE 10. *1½-inch drawn-brass-tubing trap.*

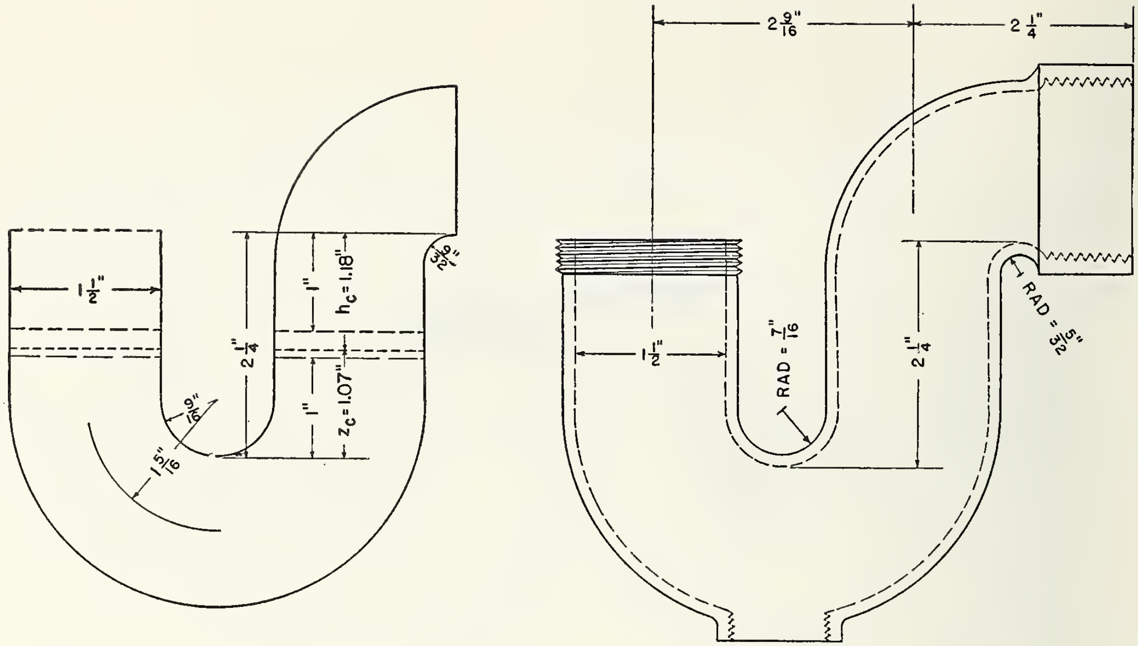

FIGURE 11. *1½-inch cast-brass trap.*

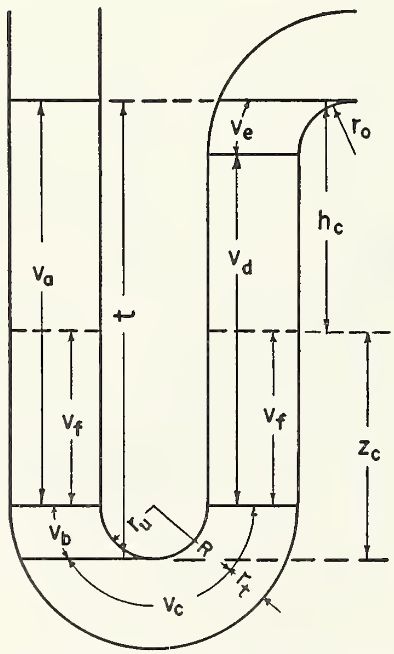

FIGURE 12. *Trap for theoretical discussion.*

The initial volume of water in the trap is

$$V_a+V_b+V_c+V_d+V_e.$$

The volume of water lost when the water level in the inlet leg is drawn down to the level of the dip of the trap is V_a+V_b. Then, when the pressure again equalizes, the final volume of water in the trap is the same as it was after the volume V_a+V_b was lost, or is

$$V_c+V_d+V_e=2V_f+V_b+V_c.$$

But we have assumed that $V_b=V_e$. Hence

$$2V_f+V_b+V_c=V_c+V_d+V_b.$$

Then

$$V_f=\frac{1}{2}\,V_d.$$

V_d is the volume of water contained in the cylindrical portion of the outlet leg of the trap, and hence the height of the cylinder occupied with the volume V_f is half the height of the cylindrical portion of the leg.

1¼-inch adjustable trap (*see fig. 7*). The height of the cylindrical portion of the outlet leg is $t-r_u-r_o$, where r_u is the radius of curvature of the the lower bend, and r_o is the radius of curvature of the upper bend (see fig. 12). Hence for this trap we have for the height in question: $2-{}^{17}\!/_{32}-{}^{1}\!/_{2}={}^{31}\!/_{32}$ inch or 0.969 inch. Then $h_c={}^{31}\!/_{32}\div 2+{}^{1}\!/_{2}=0.985$ inch.

1¼-inch brass tubing trap (*see fig. 8*). $t-r_u-r_o=3\,{}^{3}\!/_{16}-{}^{15}\!/_{16}-{}^{13}\!/_{16}=1\,{}^{7}\!/_{16}$ inches$=1.437$ inches. Then $h_c=1.437/2+{}^{13}\!/_{16}=1.53$ inches.

1¼ inch cast-brass trap (*see fig. 9*). $t-r_u-r_o=1\,{}^{3}\!/_{4}-{}^{17}\!/_{32}-{}^{11}\!/_{32}={}^{7}\!/_{8}$ inch$=0.875$ inch. Then $h_c=({}^{7}\!/_{8})/2+{}^{11}\!/_{32}={}^{25}\!/_{32}$ inch$=0.782$.

1½ inch drawn brass trap (*see fig. 10*). $t-r_u-r_o=3\,{}^{9}\!/_{16}-{}^{17}\!/_{16}-{}^{25}\!/_{32}=1\,{}^{23}\!/_{32}$ inches$=1.697$ inches. Then $h_c=1.697/2+{}^{25}\!/_{32}=1\,{}^{41}\!/_{64}$ inches$=1.641$ inches.

1½ inch cast brass trap (*see fig. 11*).

In computing the critical trap-seal loss for this trap, it was assumed that the outlet leg is cylindrical from the downstream end of the U-bend to the level of the trap weir. Then (see fig. 12),

$$V_a = V_d + V_e,$$

and the volume of water lost when the level in the inlet leg is drawn down to the level of the dip of the trap is $V_a + V_b$.

The volume of water, V_b, lost from the U-bend was computed by an approximate process and was found to be, for this particular trap, equal to the volume of a torus having a central angle of about 30°. That is, for this particular trap, the volume would be $(30/360)(2\pi^2 R r_t^2) = 0.0833 \times 2 \times 9.88 \times 1.313 \times 0.75^2 = 1.215$ cubic inches. See figure 12 for the notation used in the last equation.

As the radius of the trap tube is 0.75 inch, this corresponds to a water column 0.69 inch long in the cylindrical portion of the tube. The water level is then at a distance of 1.07 inches above the dip of the trap, and the critical trap-seal loss is 1.18 inches.

6. Analysis of the Problem

6.1. General Considerations

The discussion in earlier sections of this paper of the phenomenon of trap-seal losses due to self-siphonage has made it clear that we are concerned with an extremely complicated problem, one which defies analytical treatment. Not only are there many variables on which trap-seal losses depend, but in addition we are not interested in what happens in the trap when a steady state of flow has been established, but rather in what occurs under transient conditions, that is, when the discharge from the fixture ceases.

When a physical problem is too difficult for analytical treatment, one resource is to utilize dimensional analysis to establish the particular dimensionless variables that may affect the result and then indicate that there exists a functional relation between them:

$$\phi[\pi_1, \quad \pi_2, \quad \pi_3, \quad \ldots \quad \pi_{n-i}] = 0, \tag{2}$$

where the π's are different dimensionless quantities built up from the pertinent physical quantities, and $\phi[\ \ldots\ ] = 0$ denotes that a functional relation exists between them. The experiments are then planned to develop this functional relation [8, 9, 10].

However, the system with which we are dealing in this investigation was too complicated to permit a single functional relation to be developed that would include all of the dimensionless variables that were involved under different conditions. This can perhaps be appreciated by a more detailed consideration of the system, see figure 2.

We see that when the fixture discharges into the continuous waste and vent, the water flows successively through these parts of the system: (1) Outlet orifice and down pipe, (2) trap, (3) drain, and (4) vent fitting. It will be assumed that the diameter of the continuous waste and vent is adequate to carry the flow properly, and of course it is vented. Hence it should have no measurable effect on the trap-seal losses. We shall also assume for simplicity that the diameter of the down pipe is the same as that of the outlet orifice.

Now the flow out of the fixture may possibly be determined by any one of the four portions of the system outlined above. In other words, any one of the four portions of the system may be the "critical" part. Furthermore, each portion of the system will give rise to a characteristic Froude number, since the acceleration of gravity is the impelling physical force that produces the flow. But for any given set of conditions only one of these Froude numbers will be involved, since the Froude number characteristic of that portion of the system that is critical under the given conditions is the pertinent one. However, there is no simple way of establishing a functional relationship that, under a given set of conditions, will bring in one characteristic of one part of the system and exclude others, while, under a different set of conditions, will bring into play a different Froude number and exclude the others.

Furthermore another somewhat similar complication was found in the fact that, under certain conditions the slope, S, of the drain was involved to the first power, while under other conditions it was involved to the one-half power.

Again, the form of the fixture played an important part in determining the magnitude of the trap-seal losses. A flat-bottomed fixture produced a long-continuing trail discharge that tended to replenish the trap and so reduce or completely prevent trap-seal losses. On the other hand, a deep, narrow fixture that caused very little trail discharge tended to produce large trap-seal losses because of the slight degree to which the water lost from the trap was replenished in this way. Under these conditions, the results obtained were valid only for the particular shape and size of the fixture used.

In view of the complications of the problem, it seemed that the only goal that was feasible to set was that of determining what combinations of dimensionless variables, under given conditions, would bring order out of the data and to show that these particular variables had a rational basis. The development of these variables and their rational basis will be presented shortly.

In fact, as so often happens, some of these variables had been found by cut-and-try methods before their rational basis had been shown. This was due to the fact that heavy pressure was placed upon us to get practical results at the earliest possible date to be used in preparing certain sections of the Uniform Plumbing Code [11]. Because of this pressure, it was only when the results were being written up finally that time could be taken to make an adequate analysis of the problem. As a result, the tests were not designed to get the maximum amount of information from them. However, the practical results that were desired were obtained sooner in this way than if time had been taken to make a preliminary analysis.

A little consideration of the transient aspects of the problem is required next in order to justify the establishment of the characteristic dimensionless numbers for the different parts of the system under assumptions of steady flow, whereas the trap-seal loss occurs only because of the cessation of the flow. Fundamentally, the trap-seal loss is due to the rate of flow through the system at the moment when the flow may be said to cease. However, "the moment when the flow may be said to cease" is a rather vague concept, as can be seen from figure 3. Practically, we might take this point as that at which the vortex begins or that at which the vortex flow ceases and film flow begins.

When the flow ceases, the trap-seal loss that results is primarily due to the inertia of the water, except as other factors, such as the resistance to flow offered by the drain and the occurrence of trail discharge, are concerned.

This rate of flow, Q, may depend on any of the characteristics of the system: diameter and shape of the outlet orifice; length and diameter of the down pipe; diameter and shape of trap; diameter, length, slope, and roughness of the fixture drain; and size and shape of vent fitting. The trap-seal loss, then depends on all of these quantities, since it is a function of Q, and it also depends on some additional quantities that do not affect Q at all, or not measurably, such as the depth of trap seal and the trail discharge.

It is a simple matter to include the depth of trap seal in the list of physical quantities and to use it in forming a dimensionless variable, but it is not so simple to include the effect of trail discharge, since the latter may affect the trap-seal loss through the rate at which it decreases to zero. Hence we recognize the trail discharge as one quantity with which we cannot operate formally, and we specify that the trap-seal losses that are found with a particular shape and size of fixture apply only when that fixture, or a fixture similar to it in size and shape, is used.

6.2. Derivation of the Applicable Dimensionless Variables

We can treat the system as a whole in doing this, simply listing all of the physical and geometrical factors that we believe may affect the trap-seal loss and then using the method of dimensional analysis to form the corresponding dimensionless variables, each of which must then be considered in turn, so that we may determine from our knowledge of the physics of the problem which of them may be omitted from consideration as having no appreciable effect on the phenomenon in which we are interested.

However, it will probably be clearer if we consider the individual parts of the system in doing this, discussing each of the dimensionless variables that apply to that part of the system before passing on to the next part of the system.

a. Trap-Seal Loss

It has already been pointed out that the trap-seal loss should be introduced as a dimensionless ratio if we use the method of dimensional analysis, and the logical form of this ratio is h/t, where h is the trap-seal loss (it could equally well be taken as the remaining trap seal if we chose), and t is the initial depth of trap seal, that is, the vertical distance from the level of the trap weir to the level of the dip of the trap.

b. Orifice Outlet and Down Pipe

The volume rate of flow out of the lavatory or other fixture, which is the fundamental quantity that affects trap-seal loss, depends on the geometry of the outlet orifice and down pipe, on the rate of air entrainment from the overflow outlet, and on the head of water from the water surface in the fixture to the lowest section of the down pipe. This head will not be exactly equal to the vertical height of the water column between these two levels because (1) the pressure at the bottom section of the down pipe will not be atmospheric under most conditions of flow, while the pressure on the surface of the water in the fixture is atmospheric, and (2) the entrained air in the column of water under consideration will cause the density of the mixture of air and water in this pipe to differ from that of the water alone.

These effects are too complicated to analyze for our present purpose, but we can write down the principal dimensionless variable, that is, the one that has the greatest effect on the outflow and hence on the trap-seal loss.

The general equation for flow from an orifice is

$$Q = CA\sqrt{2gH}, \tag{3}$$

where

Q = the volume rate of flow
C = an empirical dimensionless coefficient
A = the cross-sectional area of the orifice
g = the acceleration of gravity
H = the vertical distance from the water surface in the fixture to the lowest section of the down pipe, corrected for any deviation from atmospheric pressure that may exist at the latter section.

For our present purpose, it will be more convenient to characterize the area of the orifice opening by its diameter, d_o, than by its area, A. Hence eq 3 can be written

$$\frac{Q}{d_o^2\sqrt{gH}} = C'. \tag{4}$$

The left member of eq 4 is dimensionless and, in fact, is the particular form of dimensionless variable that we call the Froude number, since it involves the force of gravitation through the acceleration g. Thus the Froude number that applies to the outlet orifice and down pipe is $Q/d_o^2\sqrt{gH}$.

As the down pipe is short and is vertical, we need not consider the effect of friction on the flow in this part of the system. Note that, for simplicity, we have assumed that the diameter of the down pipe is the same as that of the outlet orifice.

c. Fixture Trap

In considering the flow through the fixture trap, we are led to the conclusion that the following quantities are the principal ones that may affect the trap-seal loss:

Q=volume rate of flow
g=acceleration of gravity
d_t=diameter of the trap
t=depth of trap seal
f_t=effective friction and bend loss coefficient that is characteristic of the trap.

Other dimensions of the trap are involved, but probably to a much less degree than the diameter of the trap and the depth of trap seal. These other dimensions will be ignored, and it will be recognized that the results obtained with any particular trap are valid only for that size and shape of trap.

f_t is in the form of the Darcy-Weisbach dimensionless friction coefficient and includes both the loss due to surface friction and the bend loss, the latter being assumed to be distributed uniformly over the developed length of the trap.

Hence we have $n=5$ physical quantities involved in flow through the trap: Q, g, d_t, t, and f_t. These quantities can be expressed in terms of $i=2$ physical dimensions—length and time—and according to the theory of dimensions, they will combine into $n-i=3$ independent dimensionless variables,

$$\frac{Q}{d_t^2\sqrt{gt}},\quad \frac{t}{d_t},\quad \text{and } f_t.$$

The first of these variables is a Froude number, which is present because, as has already been pointed out, the force of gravity is the predominating physical force involved in the phenomenon of flow through traps. While the given combination of quantities, Q, g, d_t, and t, is adequate to form this dimensionless Froude number, the theory of dimensions affords no assurance that the above is the exact combination that should be used, as regards the way in which d_t and t enter the number. All that the theory of dimensions tells us in regard to these lengths is that they must enter in such a combination as to have the dimensions of $(\text{length})^{5/2}$.

However, by drawing on our knowledge of the physics of the phenomenon, we can at least get a suggestion as to the form of the Froude number that is characteristic of the trap.

We note that the ratio, Q/d_t^2, is proportional to the mean velocity, v_t, of the flow through the trap, assuming that the outlet leg of the trap is flowing full. We also note that $\sqrt{gt}$ is a velocity, and more specifically, it is proportional to the velocity of free fall that would be attained by the water in falling through the distance t. Thus the dimensionless variable, $Q/d_t^2\sqrt{gt}$, may be looked upon as the ratio of two velocities, one tending to empty the trap and the other tending to keep it filled. Thus we find that there is a rational basis for this particular form of the variable, and we should expect, therefore, that there might be found some relation between the trap-seal loss and this ratio when the trap is the controlling factor in the flow phenomena in the system.

As a matter of pure expediency, a change was made in this Froude number by replacing t by t_1, in plotting the results of certain tests, since it was found that this appeared to yield less scatter of the observed points than did the use of the quantity t. The relation between t and t_1 is

$$t_1=t+d_t/2,$$

as can be seen from figure 1.

The variable t/d_t takes into account the relative proportions of the trap but is not sufficient to specify the shape of the trap. Two quantities that obviously should be added to the list of significant quantities if we were studying the effect of changes in the shape of the trap are the radius of curvature of the U-bend at the bottom of the trap and the radius of curvature of the bend at the outlet end. Even the addition of these variables does not suffice to permit an analysis to be made of the effect of changes in the shape of an actual trap, because there are other minor differences between the traps used, as can be seen from figures 7 to 11, inclusive. Neither were the variations made in the test conditions sufficient to permit an analysis of the effect of varying the dimensions of the traps to be made, nor was this the purpose of the tests.

The quantity f_t, as has already been stated, is a dimensionless friction factor analogous to the Darcy-Weisbach friction factor, f, which is defined by the equation

$$H=f\frac{l}{d}\frac{v^2}{2g}. \tag{5}$$

This equation represents the friction head loss, H, in a straight full pipe of length l and diameter d when a fluid is flowing through the pipe with the average velocity v. If the pipe is curved, there will be another loss of head, $\alpha v^2/2g$, where the coefficient α will vary with the geometry of the curvature. If we add these two losses, we have the result

$$H=\left(\alpha+f\frac{l}{d}\right)\frac{v^2}{2g}. \tag{6}$$

We can replace the quantity in the parenthesis by a single coefficient f_t in applying the equation to fixture traps.

It was not feasible to investigate the effect of variations in the coefficient f_t, nor would such an investigation have proved fruitful if carried out, since other and probably far more important factors that affect the trap-seal losses were present, and since it is of more practical importance to standardize traps than to make exhaustive tests to determine the best possible proportions. Hence the quantity f_t will be left out of consideration in the analysis of the data.

d. Fixture Drain

The physical quantities that affect flow through the fixture drain are

Q=volume rate of flow
g=acceleration of gravity
l=length of the drain
d_2=diameter of the drain
S=slope of the drain
f_d=friction factor applying to the drain.

Considerations of dimensional analysis yield the following four dimensionless variables:

$$\frac{Q}{d_2^2\sqrt{gd_2}}, \frac{l}{d_2}, S, f_d.$$

There is no question as to the form of the Froude number, $Q/d_2^2\sqrt{gd_2}$, in connection with the drain, since the only other length than d_2 that could enter this variable is the length of the drain l, and it is hardly conceivable that this length would be involved in this particular variable.

The variable, l/d_2, is always present in pipe-flow problems, and so it would be expected that it would be involved here.

However, a study of the data brought out the fact that if we plot $Q/d_2^2\sqrt{gd_2}$ against l/d_2, we obtained a separate curve for each value of the slope S, while if, for some of the tests, we plotted this Froude number against Sl/d_2 the curves, for the most part, coalesced into a single curve; while, for other tests, plotting the Froude number against $S^{1/2}l/d_2$ made the points coalesce into a single curve. In no instance did the points form a clean-cut curve, but rather they came nearer to combining to form a definite curve by plotting against one or the other of the two variables mentioned than if plotted against some other power of S. This fact led to a further investigation of the problem.

We start with the following Chezy formula for flow in open channels, which is the case we have when the drain is flowing only partly full:

$$v=C\sqrt{d_2S}, \tag{7}$$

where v=the velocity of flow in the drain
C=a constant
d_2=the diameter of the drain
S=the slope of the drain.

We can modify this equation to make it dimensionally correct by inserting g, the acceleration of gravity, and at the same time we multiply v by the cross-sectional area A of the stream in the drain in order to obtain the volume rate of flow Q:

$$Q=C'A\sqrt{gd_2S}. \tag{8}$$

We further modify the equation by replacing A by some constant multiplied by the diameter squared and absorbing all the constants in a new constant C'':

$$Q=C''d_2^2\sqrt{gd_2S}. \tag{9}$$

This leads us to the product of two dimensionless numbers, the first of which is the Froude number previously obtained by the methods of dimensional analysis, $Q/d_2^2\sqrt{gd_2}$, and $1/S^{1/2}$.

If we start with the Darcy-Weisbach formula for friction loss in pipes flowing full,

$$H=f\frac{l}{d_2}\frac{v^2}{2_g}, \tag{5}$$

we arrive at the same result.

By this process of reasoning, combined with what the theory of dimensions told us, we arrive at the variables,

$$\frac{Q}{d_2^2\sqrt{gd_2S}}, \frac{l}{d_2}, \quad S, \quad \text{and } f_d.$$

For reasons that will be explained shortly, we shall not retain the friction factor f_d, so that we are concerned merely with the three variables remaining. These are not in exactly the form in which we were led by empirical methods to plot the data, but we can modify these variables to obtain the form actually used, owing to the fact that it is permissible to combine the pertinent dimensionless variables as we wish. Hence we can multiply $Q/d_2^2\sqrt{gd_2S}$ by $S^{1/2}$ to obtain $Q/d_2^2\sqrt{gd_2}$, and likewise we can multiply l/d_2 by either $S^{1/2}$ or by S to obtain $S^{1/2}l/d_2$ or Sl/d_2, thus having finally one or the other of the two following groups of dimensionless variables:

$$\frac{Q}{d_2^2\sqrt{gd_2}}, \quad \frac{Sl}{d_2}, \quad S;$$

or

$$\frac{Q}{d_2^2\sqrt{gd_2}}, \quad \frac{S^{1/2}l}{d_2}, \quad S.$$

This merely shows that there is a rational basis for the use of the groups of variables listed above, although these variables were originally selected for plotting the data by purely empirical means.

e. Vent or Stack Fitting

Two forms of vent or stack fittings are commonly used in installations such as we discuss in this paper—the long-turn fitting and the short-turn fitting. Furthermore there will be variations in each of these two fittings in that for a given vent or stack diameter the drain diameter, and hence the diameter of the side inlet of the branch fitting, may be equal to or less than the vent or stack diameter. Hence flow through the side inlet of the branch fitting will lead to at least the following dimensionless variables:

$$\frac{Q}{d_2^2\sqrt{gd_2}},\ \frac{d_1}{d_2},$$

plus other length ratios that specify the shape of the fitting.

It will be noticed that the variable, $Q/d_2^2\sqrt{gd_2}$, is identical with the Froude number which characterizes flow in the fixture drain, and hence no new Froude number is added thereby to the two already listed. The other variables all have an effect on trap-seal losses, but it was not feasible to investigate the effects of each separately, nor was this contemplated within the scope of this investigation. Hence the data were treated separately for the long-turn and the short-turn fittings, the only two used in this investigation.

6.3. Effect of the Density of the Air and the Water

The ratio of the density of the atmospheric air to that of water will obviously affect trap-seal losses. However, if this ratio is constant, or very nearly so, these two physical quantities can be ignored, and their effect will be absorbed in the errors of the observed results.

Changes in air density at a given locality will be appreciable but will have very little effect on the trap-seal losses, since air is only about one-thousandth as dense as water. Changes with altitude will also be appreciable but will have little effect for the same reason.

Water, if unmixed with air bubbles, will have a density which, for the purposes of this invesitgation, can be considered constant. However, it was observed in many of the tests of lavatory self-siphonage in which transparent plastic traps and drains were used that, during the discharge of the fixture, air was aspirated from the overflow connection above the trap into the water flowing through the trap and drain. In addition, a vortex usually formed in the fixture near the end of its period of discharge, with consequent flow of air into the system. For these reasons the effective density of the air-water mixture flowing through the traps and drains of plumbing fixtures is not constant but varies with the type of fixture and also to some extent, at least, during the period of discharge of the fixture.

6.4. Summary

Summarizing, we may list the dimensionless variables with which we may be concerned in dealing with the problem of self-siphonage as follows:

$$\frac{h}{t},\ \frac{Q}{d_t^2\sqrt{gt}},\ \frac{t}{d_t},\ \frac{Q}{d_o^2\sqrt{gH}},\ \frac{Q}{d_2^2\sqrt{gd_2}},\ \frac{S^a l}{d_2},\ S,$$

in which a may take on a value of either unity or one-half.

We express the fact that there is some functional relation between these variables by writing:

$$\text{function}\left(\frac{h}{t},\ \frac{Q}{d_t^2\sqrt{gt}},\ \frac{t}{d_t},\ \frac{Q}{d_o^2\sqrt{gH}},\ \frac{Q}{d_2^2\sqrt{gd_2}},\ \frac{S^a l}{d_2},\ S\right)=o.$$

7. Experimental Investigation

7.1. Description of the Test System

In this investigation the tests were made, for the most part, with standard plumbing fixtures connected to complete drainage systems, as shown in figures 13 and 14. The building sewers of these systems were connected to an 8-inch-diameter street sewer, in which the flow could be varied up to 300 gallons per minute and which could be made to flow completely or partially filled at will. In these systems the stacks and some of the fixture drains were made of transparent methacrylate plastic tubing and fittings. However, the transparent parts of the system were used primarily to enable us to see the flow phenomena that occurred in connection with self-siphonage, and the final test results were obtained with the conventional metal pipes and fittings. Still another system—the one shown in figure 15—was used to study systematically the effect of the volume rate of flow through the fixture trap and drain as well as lengths, shape, and diameter of drain and type of

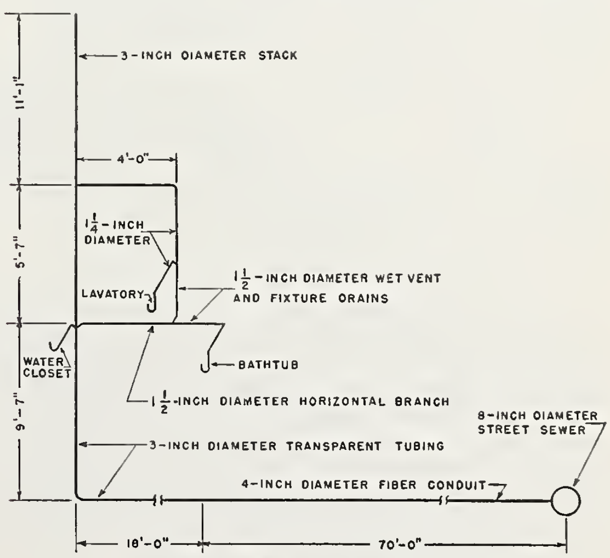

Figure 13. *Wet-vented test system.*

vent fitting on the trap-seal reduction. This last system was a more severe test of the ability of fixture traps to resist self-siphonage than the other two systems, in which actual plumbing fixtures were attached to the system and discharged. This is due to the fact that some trail discharge occurred when actual fixtures were used, and this trail discharge tended to replace any water lost from the trap as a result of the main part of the discharge. When the system shown in figure 15 was used, there was virtually no trail discharge.

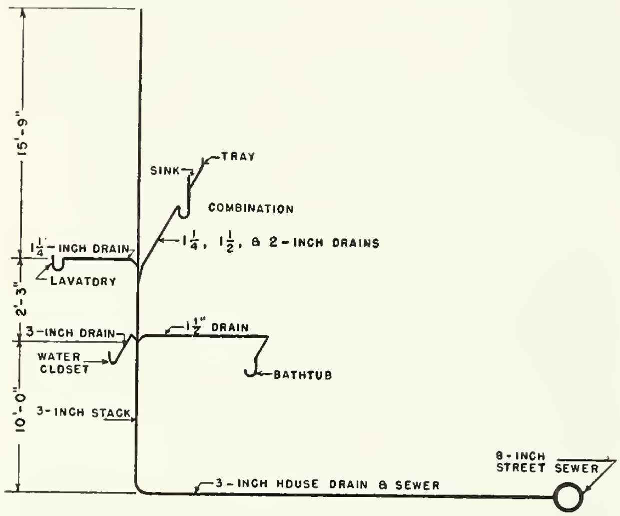

FIGURE 14. *Stack-vented test system.*

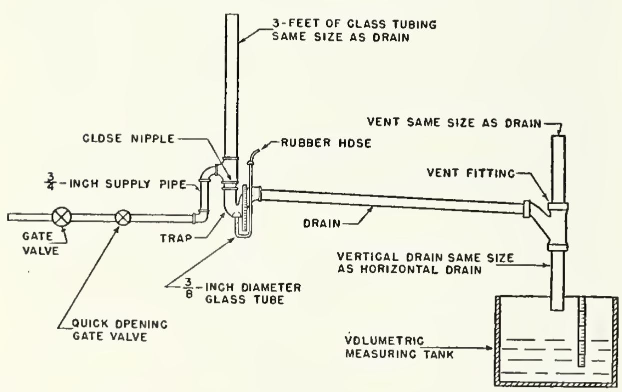

FIGURE 15. *Arrangement of apparatus for "no-trail" discharge tests.*

7.2. Test Procedure

In the self-siphonage tests the fixture was filled and then was allowed to drain either by pulling the plug from the outlet orifice or, in the case of the water closet, by operating the flush valve. With the lavatories, bathtubs, and sinks, trap-seal losses were measured by means of a small water manometer connected to the trap through the clean-out, and in the case of water closets by simply measuring down to the water surface from a horizontal reference plane.

7.3. "No-trail" Discharge Tests

In the usual discharge of a fixture we have, at the end of the discharge, a condition that is called "trail discharge" and described in section 2. As the discharge from the fixture nears its end, the rate of discharge decreases rapidly (see fig. 3) owing to the formation of a vortex over the outlet orifice. In addition, an appreciable amount of water adheres to the inner surface of the fixtures, and this slowly drains out of the fixture after the vortex has ceased.

In order to simplify the initial study of the phenomenon of self-siphonage by eliminating some of the complications due to this trail discharge, an investigation of the effects of rate of discharge, and of the length, slope, and diameter of the fixture drain, in particular, on self-siphonage, a number of tests were made with the system shown in figure 15 in which trail discharge was prevented from occurring. These tests will be referred to as "no-trail" discharge tests. In these tests trail discharge was prevented, or reduced to a minimum, by producing a constant flow through the supply pipe and then stopping this flow abruptly by means of a quick-closing valve.

The traps used in this part of the investigation are shown in figure 16. They included a 2-inch cast-steel trap having a depth of trap seal of 1¾ inches, a 1½-inch drawn-brass-tubing trap having a depth of trap seal of 2½ inches, a 1½-inch cast-brass trap having a depth of trap seal of 2⅜ inches, and a 1¼-inch cast-brass trap having a depth of trap seal of 2 inches. Thus all of the traps used in these tests were relatively shallow traps.

The results obtained in these tests are given in figure 17 for long-turn vent fittings and in figures 18 and 19 for straight-tee fittings. The results are plotted in the form of dimensionless variables, since in this way a number of individual curves for different slopes are brought together into a single curve. The utility of such a curve can be shown in the following manner.

Suppose we want to compute the maximum permissible unvented length of 2-inch drain on a ½-inch-per-foot slope for a fixture having an average rate of discharge of 13.2 gallons per minute and having little or no trail discharge. This last-mentioned condition is a very severe one and restricts sharply the permissible unvented length of drain. We shall assume that a long-turn vent fitting will be used to connect the fixture drain to the vent and that the trap shown in figure 16, A (2-inch cast steel) is to be used with the fixture. Then $d_t=1.99$ inches, $t=1.75$ inches, $d_2=2.07$ inches, and $t_1=2.78$ inches. The corresponding values in feet are $d_t=0.166$, $t_1=0.232$, and $d_2=0.1725$. The slope is $\frac{1}{24}$ foot per foot. The average rate of discharge is $Q=0.0294$ cubic foot per second. All quantities are reduced to foot-second units before they are substituted in the variables in figure 17.

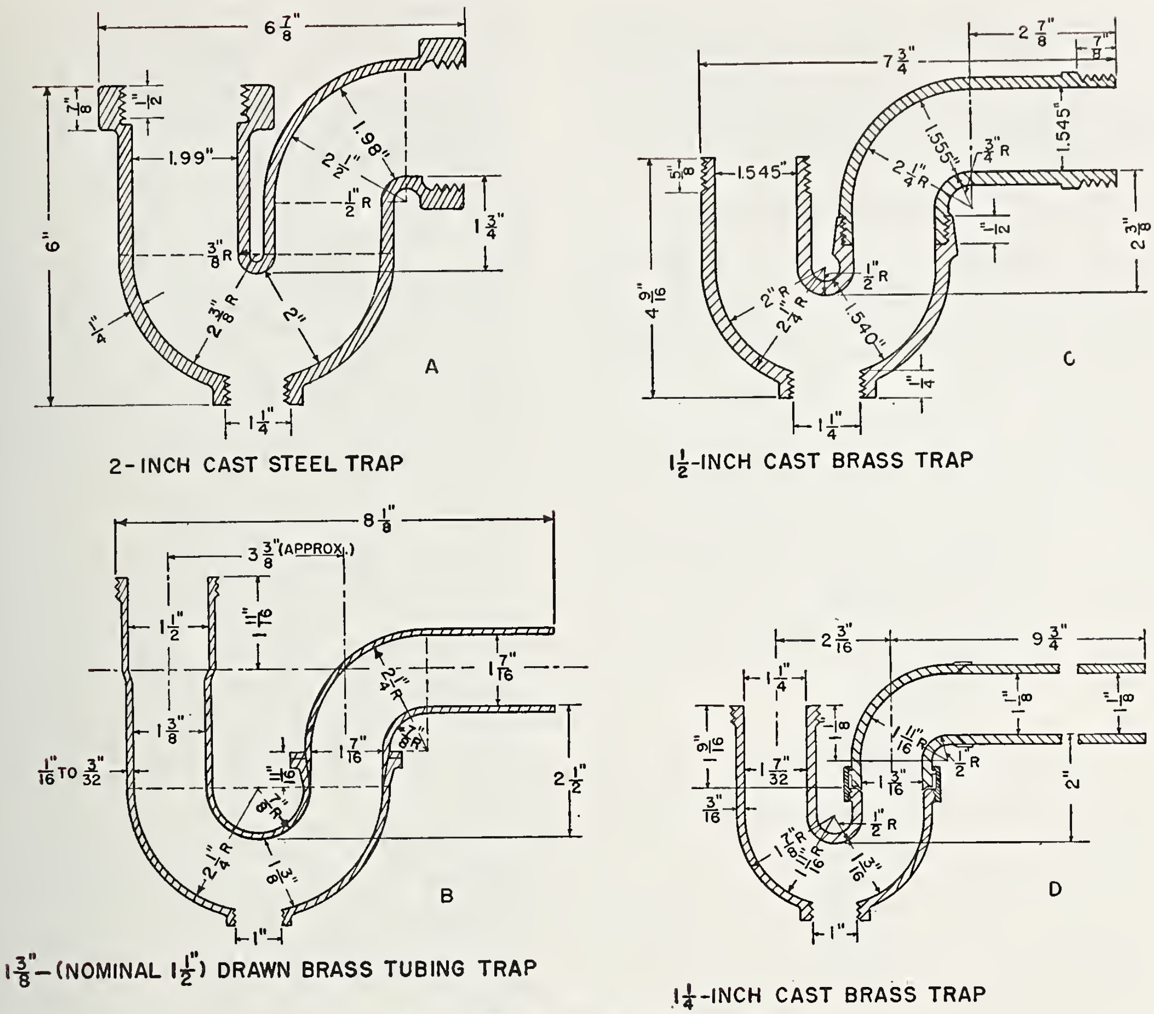

FIGURE 16. *Traps used in this investigation.*

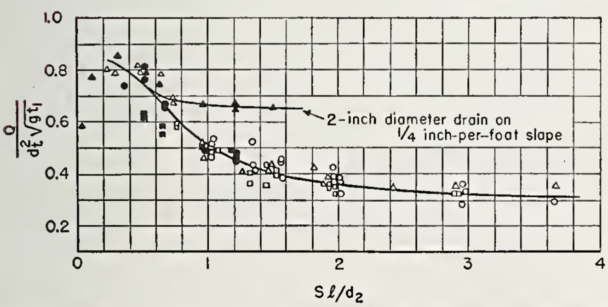

FIGURE 17. *Curves for computing maximum permissible unvented lengths of fixture drains.*

Relation between $\frac{Q}{d_t^2\sqrt{gt_1}}$ and $\frac{Sl}{d_2}$ for $h/t=0.5$. Long-turn vent fitting.

Symbol	S	d_t Nominal	d_t Actual	d_2 Nominal	d_2 Actual	t	t_1	Figure
	In./ft.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	
△	3/8, 1/2, 3/4	2	1.99	2	2.07	1.75	2.78	16, A
▲	1/4	2	1.99	2	2.07	1.75	2.78	16, A
○	3/8, 1/2, 3/4	1½	1.54	1½	1.61	2.38	3.18	16, C
●	1/4	1½	1.54	1½	1.61	2.38	3.18	16, C
□	3/8, 1/2, 3/4	1½	1.38	1¼	1.38	2.50	3.19	16, B
■	1/4	1½	1.38	1¼	1.38	2.50	3.19	16, B

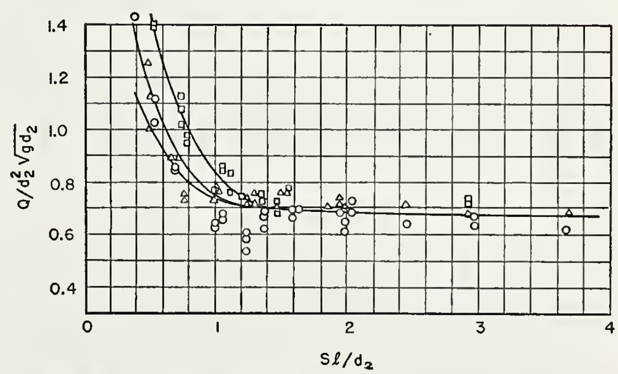

FIGURE 18. *Curves for computing maximum permissible unvented lengths of fixture drains.*

Relation between $\frac{Q}{d_2^2\sqrt{gd_2}}$ and $\frac{Sl}{d_2}$ for $h/t=0.5$. Straight tee vent fitting. Slopes of fixture drain 1/4, 3/8, 1/2, 3/4 inch per foot.

Symbol	d_t Nominal	d_t Actual	d_2 Nominal	d_2 Actual	t	t_1	Figure
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	
△	2	1.99	2	2.07	1.75	2.78	16, A
○	1½	1.54	1½	1.61	2.38	3.18	16, C
□	1½	1.38	1¼	1.38	2.50	3.19	16, B

Substituting the above values of Q, d_t, t_1, and the value of g (32.2 feet per second per second in the quantity $Q/d_t^2\sqrt{gt_1}$, we obtain the value 0.39. Entering figure 17 with this value of the ordinate, we read the corresponding value of the abscissa, $Sl/d_2=1.56$. From this last expression we have

$$l=1.56\ d_2/S=1.56\times 0.1725\times 24=6.46 \text{ feet.}$$

Another result that can be obtained from the same curve is the following: If we assume that the curve is asymptotic to the value, $Q/d_t^2\sqrt{gt_1}=0.3$, we can compute a limiting value of Q, below

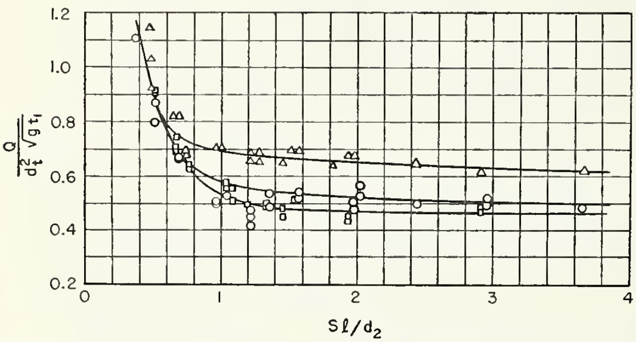

FIGURE 19. *Curves for computing maximum permissible unvented lengths of fixture drains.*

Relation between $\frac{Q}{d_t^2\sqrt{gt_1}}$ and $\frac{Sl}{d_t}$ for $h/t=0.5$. Straight tee vent fitting. Slopes of fixture drain ¼, ⅜, ½, ¾ inch per foot.

Symbol	d_t		d_2		t	t_1	Figure
	Nominal	Actual	Nominal	Actual			
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	
△	2	1.99	2	2.07	1.75	2.78	16, A
○	1½	1.54	1½	1.61	2.38	3.18	16, C
□	1½	1.38	1¼	1.38	2.50	3.19	16, B

which the trap-seal loss will never exceed $h/t=0.5$, no matter how long the drain may be. Substituting the values of d_t, t_1, and g in $Q/d_t^2\sqrt{gt_1}$, and solving the following for Q,

$$Q=0.3d_t^2\sqrt{gt_1},$$

we obtain $Q=0.0226$ cubic foot per second, or 10.15 gallons per minute.

If a straight tee is used instead of a long-turn T-Y, we use the curves in figure 18 or 19 to make computations similar to those given above.

The straight-tee vent fitting used in part of these tests was the conventional malleable-iron straight tee, and it was used merely because it represented one limiting condition for the vent fitting, that is, completely free efflux of water from the drain was permitted without any possible interference from an upper lip, such as would occur with a long-turn drainage fitting and to a lesser extent with a short-turn drainage fitting. It would be expected that test results for the short-turn fitting would lie somewhere between those obtained from the long-turn fitting and the straight tee; and, as will be shown later, they are identical, for all practical purposes, with those obtained with the straight tee.

The curves in figures 18 and 19 are plotted from the same data, but in figure 18 the ordinates are based on the Froude number that applies to the fixture drain, $Q/d_2^2\sqrt{gd_2}$. In figure 19 the ordinates are based on the Froude number that applies to the trap, $Q/d_t^2\sqrt{gt}$. It is interesting to note that in figure 18, the curves for the three traps coincide for large values of Sl/d_2, while in figure 19 they coincide for small values of Sl/d_2. This appears to mean that the trap exerts a controlling influence on permissible values of Sl/d_2 when Q is large, and the drain diameter similarly influences permissible values of Sl/d_2 when Q is low. Either of these two figures can be used to compute maximum permissible unvented lengths of drain when a straight tee is used.

The advantage of the dimensionless plots given in figures 17, 18, and 19 is that a means is thus given in compact form for computing the maximum permissible unvented length of drain for different flows from the fixture, different trap-seal depths and trap diameters, and different lengths, diameters, and slopes of drain. To furnish the same information in form for immediate use would require a considerable number of tables or figures.

It should be remembered that the computations discussed above are for no-trail discharge and hence are somewhat conservative if applied to the practical cases in which more or less trail discharge does occur. The factor of safety thus introduced is offset to some unknown extent by the fact that the computations are for clean drains.

Another instance of the utility of these three figures is afforded by the curves shown in figure 20. These curves were computed with the aid of figure 19 for two cases, in both of which it is assumed that a straight tee vent fitting is used. The first case assumes: 2-inch cast-steel trap (fig. 16,A), $d_t=2$ inches, ${}_t=1.75$ inches, $t_1=2.78$ inches, $d_2=2.07$ inches, $S=½$ inch per foot. The second assumes 1½-inch cast-brass trap (fig. 16,C), $d_t=1½$ inches, $t=2.38$ inches, $t_1=3.18$ inches, $d_2=.161$ inches, $S=½$ inch per foot. Successive values of the rate of flow Q were chosen, and values of $Q/d_t^2\sqrt{gt_1}$ were computed for the first trap. Then, by the use of the highest curve in figure 19 (corresponding to the trap used), corresponding values of Sl/d_2 were read. Then, since the values of S, d_2, and Sl/d_2 were known, it was possible to compute values of l, the maximum permissible unvented length of drain. Similar computations were made for the second trap, and the results were plotted in figure 20.

In making the computations described above, it is necessary to express S in inches per inch or feet per foot, and to express the lengths, d_t, t_1, and d_2 in the same length units, inches, feet, centimeters, or whatever may be convenient.

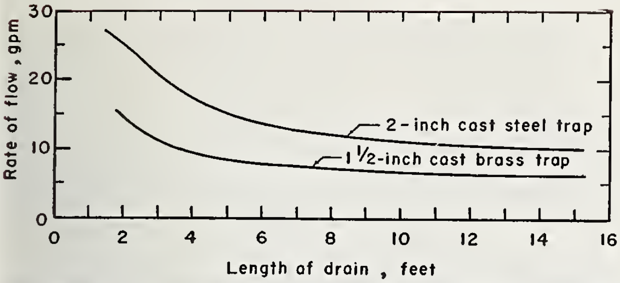

FIGURE 20. *Curves giving maximum permissible unvented lengths of drain for two traps when there is no trail discharge from the fixture to which the trap is attached.*

The curves in figure 20 show that below certain values of Q the maximum permissible length of drain is quite long, becoming infinite below some fairly definite value of Q. Hence we can make l as long as we wish by making d_2 or d_t large enough.

7.4. Lavatory Tests

The lavatory tests were made, for the most part, on the single-story stack and wet-vented systems shown in figures 13 and 14. Except for a relatively small number of tests made with the transparent plastic traps and drains, conventional metal lavatory traps, fixture drains, vent fittings, and horizontal branches were used in order that there might be no possibility of the relatively smooth plastic surfaces affecting the test results adversely.

The basic purpose of the investigation was to determine the physical and geometrical factors that affect self-siphonage and, more specifically, to determine the maximum unvented lengths of lavatory drain that might be installed without resulting excessive trap-seal losses. The tests were made by installing a lavatory with a given trap and with a given length, slope, and diameter of fixture drain, and then observing the trap-seal loss caused by discharging the lavatory. The amount of trap-seal loss was measured by means of a glass manometer tube connected to the lower bend of the trap. In the tests, the lavatory was filled to the overflow outlet. The data in table 1 show the effect of filling the lavatory to different depths. It was felt that this information would be useful, since in ordinary service the lavatory is filled to the overflow only rarely. The data indicate that the trap-seal loss will be approximately the same if the lavatory is filled to any depth of more than 3 inches and discharged.

TABLE 1. *Effect of depth to which lavatory is filled on self-siphonage of its trap*

	Trap-seal loss		Depth of water in lavatory
	Maximum of 5 test runs	Average of 5 test runs	
	Inches	*Inches*	*Inches*
Lavatory filled to overflow	1.75	0.69	4⅛
Water surface 1 inch below overflow	1.75	.85	3⅛
Water surface 2 inches below overflow	0.00	.00	2⅛

For this reason, the use of a full lavatory in the self-siphonage tests cannot be considered an excessive test load and one that would not be likely to occur in normal service.

The data obtained in one series of self-siphonage tests of a lavatory are shown in figure 21 in order to show the extent of the scatter typical of such data. In these tests a 1¼-inch cast-brass trap having a depth of trap seal of 2 inches was used with a 1¼-inch fixture drain, and a short-turn vent fitting was used. The rate of flow from the lavatory varied between an average of 10.6 to 10.9 gallons per minute in the tests. In plotting the data shown in this figure and in all subsequent plotting of data obtained from tests on actual fixtures, we have used the nominal diameter rather than the slightly larger true diameter of the fixture drain. The drain slopes used were ¼ and ½ inch per foot. Each point plotted represents the maximum observed trap-seal loss obtained in 10 consecutive tests made under identical conditions.

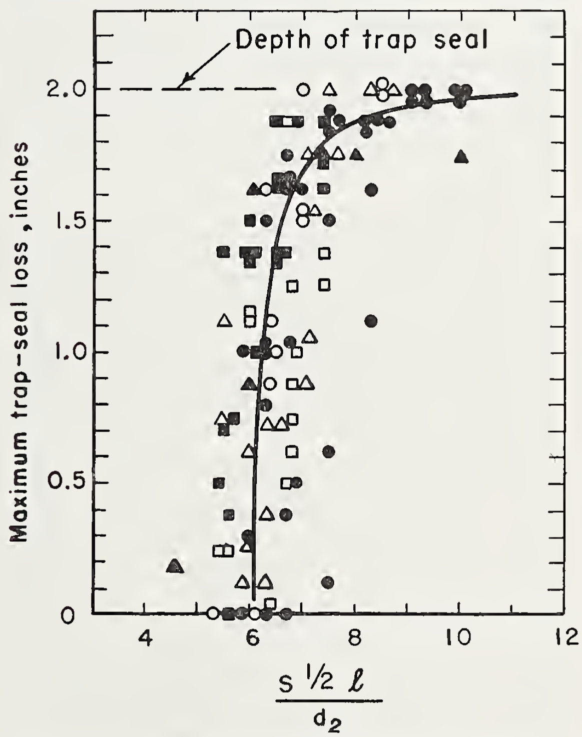

FIGURE 21. *Results of tests of lavatory self-siphonage.*

1¼-inch-diameter trap. Short-turn vent fitting. Average rate of flow from fixture 10.9 gpm. Trap used is shown in figure 16, B.

Symbol	Slope of drain, S	System used
	In./ft.	
○	¼	Figure 13. Lavatory trap, drain, and vent fitting
●	½	of metal. Remainder of system plastic.
□	¼	Same as above except wet vent, tub drain, and
■	½	horizontal branch were also of metal.
△	¼	Figure 2. Partial system, only to continuous waste
▲	½	and vent.

The scatter shown by the data in figure 21 is characteristic of most of the data obtained on lavatory self-siphonage. It will be appreciated from the discussion earlier in this paper of the action of traps when subjected to conditions that cause self-siphonage that considerable scatter is to be expected, and the only surprising thing is that it is so small.

Trial plotting of the data, using first the variable, Sl/d_2, and then $S^{1/2}l/d_2$, showed that for the tests shown in figure 21 the variable, $S^{1/2}l/d_2$, brought better order out of the data than did the other variable.

An average curve was passed through the points plotted in figure 21 and has a shape that is characteristic of tests on lavatory self-siphonage. When a critical value of $S^{1/2}l/d_2$ is reached, loss of trap seal commences abruptly and increases very rapidly at first, then more slowly, and finally approaches asymptotically the value corresponding to the depth of trap seal for the trap used.

Thus the value of the quantity, $S^{1/2}l/d_2$, at the point where the reduction in trap seal commences might serve as a basis for determining the maximum permissible unvented length of drain. Or, if a trap-seal reduction of 1 inch, for example, is settled on as the line of demarcation between satisfactory and unsatisfactory seal loss, we select the value of $S^{1/2}l/d_2$ corresponding to this. Similarly, for a remaining trap seal of 1 inch, or whatever may be chosen.

The maximum trap-seal losses obtained in the tests just discussed, as well as in three other series of tests, are shown in figure 22, with the actual data not plotted. The curve in figure 22, B, is identical with the curve in figure 21 for the test with the short-turn fitting. The curve in figure 22, A, is for the same trap and drain but with a long-turn fitting used instead of the short-turn.

Figure 22, C and D, show the results obtained with a modification of the drawn-brass tubing trap shown in figure 10. A portion of the cylindrical parts of the two legs was removed, shortening the depth of trap seal to 2.5 inches, thus changing the trap from a deep trap to one with a medium depth of seal. The curve in figure 22, C, represents the results obtained with this trap when a long-turn fitting was used, while the curve in figure 22, D, represents the results obtained with a short-turn fitting. It will be noted that the abscissas are values of the variable, Sl/d_2, for this trap, in contrast with the variable, $S^{1/2}l/d_2$, which was used in plotting the results for the other trap tested. The only reason for selecting the former variable to use in plotting the results for this trap was the fact that this procedure brought better order out of the data than did the use of the other variable.

The fact that a short-turn fitting will permit the use of longer unvented lengths of drains than will the use of a long-turn fitting is brought out clearly by a comparison of the curves in figure 22, A and B. Of course the reason that a short-turn fitting is better than the long-turn fitting in this respect is that there is less tendency for the flow in the drain to close off the passageway through a short-turn

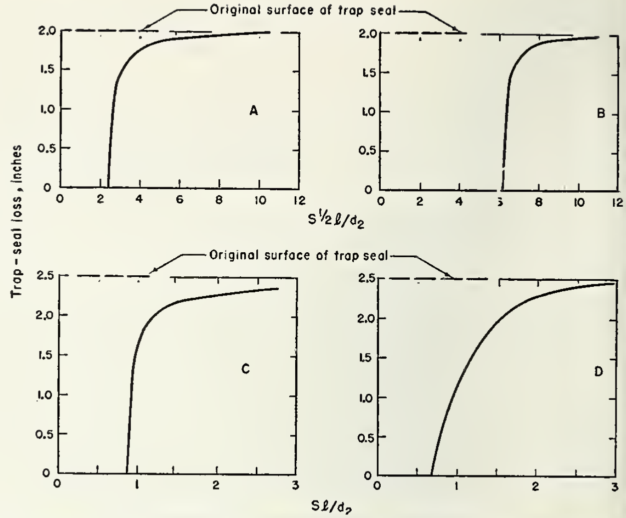

FIGURE 22. *Tests of lavatory self-siphonage for four traps.*

A

Q=10.9 gpm.
S=¼ and ½ inch per foot.
d_t=1³⁄₁₆ inches.
t=2 inches.
d_2=1¼ inches.

1¼-inch cast-brass trap. See figure 16, B. Systems used shown in figures 13 and 14. Long-turn vent fitting.

B

Q=10.6 to 10.9 gpm.
S=¼, ½ inch per foot.
d_t=1³⁄₁₆ inches.
t=2 inches.
d_2=1¼ inches.

1¼-inch cast-brass trap. See figure 16, B. Systems used shown in figures 2 and 13. Short-turn vent fitting.

C

Q=13.1 to 13.5 gpm.
S=¼, ½, ¾ inch per foot.
d_t=1⅜ inches.
t=2.5 inches.
d_2=1½ inches.

1½-inch drawn-brass tubing trap. See figure 10. Systems used shown in figures 2 and 14. The trap used was modified so that the depth of trap seal was 2.5 inches instead of 3⁹⁄₁₆ inches, as shown in figure 10. Long-turn vent fitting.

D

Q=13.1 to 13.2 gpm.
S=¼, ½, ¾ inch per foot.
d_t=1⅜ inches.
t=2.5 inches.
d_2=1½ inches.

1½-inch drawn-brass tubing trap. See figure 10. Systems used are shown in figures 2 and 13. This trap was modified as stated under figure 22, C. Short-turn fitting.

fitting than through a long-turn fitting, thus producing pressure reductions in the drain.

The two traps selected for the tests were chosen after preliminary tests had shown that they gave larger trap-seal losses than other representative P-traps of the same diameters which were on hand. Therefore, other traps of this same general type should give results that are not worse than those reported here. While it is quite possible that traps exist that would give worse results than those shown here, it is not believed that their use is sufficiently widespread to warrant basing code requirements on their performance. As will be pointed out later in this paper, the method of determining maximum permissible unvented lengths of drains by tests on traps possessing the worst self-siphonage characteristics is a wasteful and uneconomical procedure, in that for the most part, or at least a large part, of the installations, the maximum permissible lengths of drain thus determined will be unnecessarily short. However, until more uniformity in the design of traps is achieved, or until code-writing authorities are willing to complicate their codes slightly by basing maximum permissible unvented lengths of drain on the actual trap dimensions and on the particular fixture being served, we have no obvious alternative to the method proposed.

As has already been pointed out, each plotted point in figure 21 represents the maximum trap-seal loss obtained in 10 consecutive tests under identical conditions. Hence the average curve drawn through the points represents a trap-seal loss for a given value of $S^{1/2}l/d_2$ or Sl/d_2 that will occur on the average only once in each 10 times the fixture is filled to the overflow. Thus it will be seen that there is a considerable factor of safety introduced in this manner.

In computing drain lengths from the curves in figure 22, it should be remembered that S must be expressed in inches per inch or in feet per foot, not in inches per foot. Likewise, l and d_2 should be expressed in the same units, either both in inches or both in feet.

Table 2 summarizes the results shown in figure 22 for a remaining trap seal of 1 inch, rather than for a trap-seal loss of 1 inch. This is the criterion first suggested in reference [4]. However, it is an easy matter for any one to prepare from figure 22 a similar table for any other desired criterion, such as a trap-seal loss of 1 inch.

TABLE 2. *Permissible values of $S^{1/2}l/d_2$ or Sl/d_2 for lavatory drains for a remaining trap seal of 1 inch*

Trap and drain diameter	Q	Vent fitting	Maximum permissible values of $S^{1/2}l/d_2$ or Sl/d_2
Inches	*Gpm*		
1¼	10.9	Long-turn	$S^{1/2}l/d_2=2.6$
1¼	10.9	Short-turn	$S^{1/2}l/d_2=6.2$
1½	13.5	Long-turn	$Sl/d_2=1.0$
1½	13.2	Short-turn	$Sl/d_2=1.2$

The following problem illustrates the use of table 2. Assume a 1¼-inch trap and lavatory drain, the slope of the drain to be ½ inch per foot. A short-turn vent fitting will be used. How long is it permissible to make the drain without a vent?

From table 2 we find that the equation to be used is $S^{1/2}l/d_2=6.2$. $S=½$ in./ft$=1/24$ inch per inch, and $d_2=1¼$ inches, actual diameter. Then $S^{1/2}=0.204$, and $l=6.2d_2/S^{1/2}=6.2\times1.25\times\sqrt{24}=38$ inches.

Similarly, we find for the same conditions, except that a long-turn fitting is to be used: $l=2.6d_2/S^{1/2}=2.6\times1.25\times\sqrt{24}=16.0$ inches.

The above lengths are for an average discharge rate from the lavatory of 10.9 gallons per minute.

Similarly, if we wish to compute the maximum permissible unvented length of lavatory drain for a 1½-inch trap and drain, on a slope of ½-inch per foot, using a long-turn vent fitting, we use the formula

$$Sl/d_2=1.0$$
$$l=1.0\times1.25\times24=30 \text{ inches},$$

or, if a short-turn fitting is used,

$$Sl/d_2=1.2,$$

whence $l=36$ inches. These figures are for an average rate of discharge from the lavatory of 13.5 gallons per minute.

Table 3 summarizes the above results for slopes of ¼ inch per foot and ½ inch per foot. In this table it has been assumed that the permissible length of drain is such as to leave a remaining trap seal of 1 inch. Inasmuch as the venting system is ordinarily designed so that the positive or negative pressures in the system do not exceed 1 inch of water, the use of a remaining trap seal of 1 inch as a design criterion provides a safety factor of 2, since a pressure 2 inches of water in excess of atmospheric pressure in the drain will be required to force sewer gas through the trap into the building. It has been argued in the past that such a safety factor is necessary to provide, among other things, for corrosion and fouling of fixture drains, which Hunter [4] has reported will cause increased trap-seal losses. It is believed that the safety factor thus provided is ample to take care of the possible increased trap-seal losses caused by corrosion or fouling.

TABLE 3. *Maximum permissible unvented lengths of drain for a remaining trap-seal of 1 inch*

Diameter of drain and trap	Q	Fitting	Slope of drain	Length of drain	Slope of drain	Length of drain
Inches	*Gpm*		*In./ft.*	*Inches*	*In./ft.*	*Inches*
1¼	10.9	Long-turn	½	17.6	¼	25
1¼	10.9	Short-turn	½	42	¼	59
1½	13.5	Long-turn	½	33	¼	66
1½	13.5	Short-turn	½	39.5	¼	79

The conclusions in table 3 as to the maximum permissible unvented length of lavatory drains are based, as has been stated, on the assumption that the line of demarcation between satisfactory and unsatisfactory trap performance is a remaining trap seal of 1 inch. As has been noted previously, this criterion contains a safety factor to provide, among other things, for the possibility that positive pressures in the stack may be caused by the discharge of fixtures above the lavatory in question. However, in the majority of installations in service, in which the lavatory is the topmost fixture on the system, it is obvious that the trap will not be required to resist positive pressures of any magnitude. Therefore, it appears reasonable in this case, or in any installation in which the venting system is loaded considerably under capacity, to permit greater trap-seal reductions than those used in obtaining the permissible values of $S^{1/2}l/d_2$ and Sl/d_2 given in table 2.

Reference to figure 22 will show that, if a remaining trap seal of ½ inch is assumed to be adequate for lavatories on the top floor, the permissible unvented lengths of drains for installations of this nature can be increased over the values listed in table 2. To facilitate determining the maximum permissible unvented lengths of lavatory drains for this situation, assuming a minimum remaining trap seal of ½ inch, the values given in table 4 have been read from the curves in figure 22. In the judgment of the authors, these permissible values of $S^{1/2}l/d_2$ and Sl/d_2 may be used safely in all cases in which the venting system is loaded to less than half its capacity. The capacities of vents in terms of fixture units may be obtained from a previous publication of this Bureau [12].

TABLE 4. *Permissible values of $S^{1/2}l/d_2$ and Sl/d_2 for lavatory drains on the top floor of a building, assuming a remaining trap seal of ½ inch*

Trap and drain diameter	Q	Vent fitting	Maximum permissible value of $S^{1/2}l/d_2$ or Sl/d_2
Inches	*Gpm*		
1¼	10.9	Long-turn	$S^{1/2}l/d_2$=3.0
1¼	10.9	Short-turn	$S^{1/2}l/d_2$=6.6
1½	13.5	Long-turn	Sl/d_2 =1.16
1½	13.2	Short-turn	Sl/d_2 =1.58

A number of tests other than those already discussed were carried out to investigate the effect of other factors that have an influence on self-siphonage. These will be discussed in the following sections.

a. Effect of Diameter of Lavatory Drain

In practice the drain is sometimes made one nominal size larger than the trap. For this reason, among others, tests were made to determine the effect of changing the drain diameter when a given trap is used. In figure 23 are given data for the 1½-inch tubing trap shown in figure 10 (depth of trap seal, 3⁹⁄₁₆ inches; trap diameter, 1⅜ inches) connected to a 1¼-inch drain and with a 1¼ by 1½-inch short-turn vent fitting. The tests were made with the wet-vented system shown in figure 13, with the exception that the horizontal branch was 2 inches in diameter. The system was constructed of conventional metal pipe and fittings, with the exception of the 3-inch stack, which was made of transparent plastic pipe. Each plotted point represents the average of ten test runs made under identical conditions. The average rate of flow from the lavatory was 11.5 gallons per minute.

Similar tests were made with the lavatory drain increased to 1½ inches in diameter with a rate of flow of 11.4 gallons per minute from the lavatory, and no trap-seal loss was observed in any of the tests, even when the length of drain was increased to as much as 104 inches on a ¼-inch slope (Sl/d_2=1.45) and to a drain length of 93 inches on a ½-inch slope (Sl/d_2=2.58).

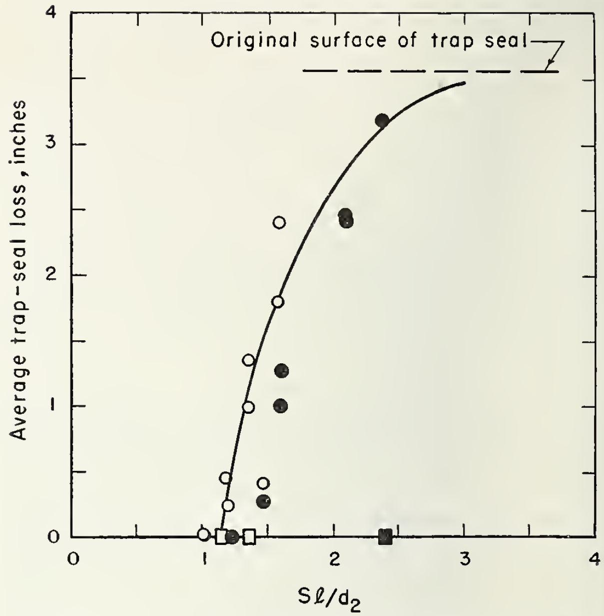

FIGURE 23. *Effect on trap-seal losses of diameter of lavatory drain.*

1¼-inch fixture drain. ○ ¼-inch-per-foot slope. ● ½-inch-per-foot slope.
1½-inch fixture drain. □ ¼-inch-per-foot slope. ■ ½-inch-per-foot slope.

It is obvious that, for a given rate of flow, decreasing the diameter of the lavatory drain will cause increased trap-seal losses. Or, stated differently, a lavatory installation in which the drain is larger than the trap will be subject to smaller trap-seal losses than a similar installation with the same trap but with the drain the same diameter as the trap.

b. Effect of Size of Lavatory

It seems reasonable to believe that the amount of trail discharge from a lavatory will bear some relation to the area and shape of its bottom surface. For this reason some of the tests were made with two different sizes of lavatories. With the 1¼-inch trap and drain, trap-seal losses were found to be practically the same whether the 18′ by 20-inch or the 20- by 24-inch lavatory was used.

However, for the 1½-inch trap and drain this was not the case. Tests made on the wet-vented system shown in figure 13 indicated that the smaller lavatory gave appreciably larger trap-seal losses than did the larger lavatory. As an illustration, tests made with the 20 by 24-inch lavatory gave an average trap-seal reduction of 0.075 inch for a drain 123 inches long on a ¼-inch-per-foot slope, while tests on the 18 by 20-inch lavatory gave an average trap-seal loss of 1.86 inches for a drain 23 inches shorter and on the same slope. The above test results are for a long-turn vent fitting and the 1½-inch tubing trap. It would be expected that a similar situation would hold for the short-turn vent fitting, back-vented or stack-vented lavatories, and for other types of traps.

c. Effect of Vertical Distance From Fixture to Trap

No tests were made during this investigation to determine the effect on the trap-seal losses of varying the vertical distance between the lavatory and the trap. However, in an earlier unpublished report [13], tests were reported in which this dimension was varied from 6 to 12 inches. These test results indicated that the effect of such variation is negligible.

d. Trap Dimensions

The principal dimensions of a trap which would be expected to affect self-siphonage are (1) the internal diameter, (2) the depth of the trap seal, and (3) the radii of curvature of the trap bends. No attempt was made to investigate these factors systematically, but sufficient tests were made to infer the effect of the first two factors.

(1) Effect of Internal Diameter of Trap. The data in figures 24 and 25 are for three traps shown in figures 7, 8, and 9. The trap diameters were 1⅛, 1³⁄₁₆, and 1¼ inches, and the drains used were all 1¼ inches nominal diameter (1.38 inches actual).

No definite conclusions can be drawn as to the superiority of either the 1⅛ inch or the 1³⁄₁₆-inch trap over the other. However, the 1¼-inch diameter trap shows a distinct superiority over the others, whether we use as our criterion the length of drain at which trap-seal losses begin, a remaining trap-seal of 1 inch, or a trap-seal loss of 1 inch. It seems highly improbable that the superiority of the trap with the largest diameter can be due either to the depth of the trap seal or to the radius of curvature of the U-bend. Hence the result is attributed to the relatively large trap diameter.

The results shown in figures 24 and 25 are summarized in table 5. The italicized values in the table indicate the trap that allowed the longest drain to be used for the given criterion.

TABLE 5. *Effect of trap diameter on trap-seal losses*

Trap in figure	Trap diameter	Depth of trap seal	Radius U-bend	Fitting	Slope drain	Length of drain for— Start of loss	1-inch seal reduction	1-inch remaining seal
	Inches	*Inches*	*Inches*		*in./ft.*	*Inches*	*Inches*	*Inches*
7	1³⁄₁₆	2	1⅛	Short-turn	¼	49	53	53
				do	½	30	41	41
				Long-turn	¼	30	36	36
				do	½	13.5	26	26
8	1⅛	3³⁄₁₆	1½	Short-turn	¼	50.5	55	64.5
				do	½	30	41	*56*
				Long-turn	¼	50.5	52	57.5
				do	½	15.5	24	40
9	1¼	1¾	1⁵⁄₃₂	Short-turn	¼	*62*	*70*	*67.5*
				do	½	*47.5*	*54*	*51.5*
				Long-turn	¼	*60*	*64.5*	*62.5*

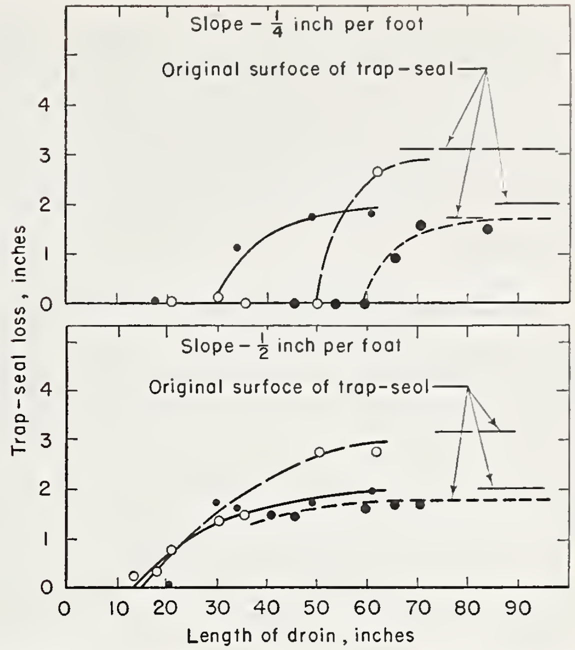

FIGURE 24. *Effect of diameter of trap used with long-turn vent fitting.*

• Trap shown in figure 7. d_t=1³⁄₁₆ inches.
○ Trap shown in figure 8. d_t=1⅛ inches.
● Trap shown in figure 9. d_t=1¼ inches.

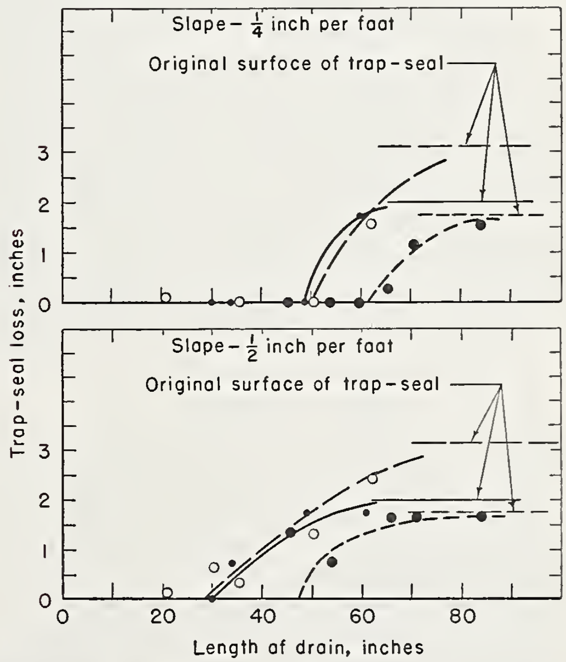

FIGURE 25. *Effect of diameter of trap used with short-turn vent fitting.*

• *Trap shown in figure 7.* d_t=*1³⁄₁₆ inches.*
○ *Trap shown in figure 8.* d_t=*1⅛ inches.*
● *Trap shown in figure 9.* d_t=*1¼ inches.*

The *italicized* values in the table indicate the particular trap and other conditions that yield the longest permissible unvented length of drain. It will be noted that, with one exception, regardless of the criterion used, the trap having the largest internal diameter is the best of the three. This is a rather surprising result, since it might have been expected that the trap with the largest depth of seal would have given the longest permissible lengths of drain for a remaining trap seal of 1 inch. This seems to indicate that the diameter of the trap has more to do with the losses due to self-siphonage than does the depth of trap seal.

(2) Effect of Depth of Trap Seal. It would be anticipated that traps with deep seals should permit longer unvented lengths of drain to be used than traps with shallow seals, provided we use as our criterion a given remaining trap seal. The same conclusion is drawn if we consider the curves in figures 17 and 19. The ordinates of these curves are values of $Q/d_t^2\sqrt{gt_1}$, from which we see that the greater the depth of trap seal t (and hence t_1, which is equal to $t+d_2/2$) the smaller is the value of this dimensionless variable, and hence the larger the corresponding value of Sl/d_2, and thus the longer the permissible unvented length of drain.

The effect of depth of trap seal was further investigated by conducting tests with the 1½-inch-(nominal)-diameter-tubing trap shown in figure 10, first with the trap shown in the figure with a depth of seal of 3⁹⁄₁₆ inches, and then with it cut down to give a depth of trap seal of 2½ inches. The installation consisted of an 18- by 20-inch lavatory connected to a stack-vented single-story system. The data were somewhat erratic but did show two things clearly: (1) that the deeper seal left a larger remaining trap seal after discharge of the fixture than did the smaller seal. For the seal depth of 3⁹⁄₁₆ inches, the maximum permissible unvented length of drain is given by the relation, $Sl/d_2=1.8$, while for the seal depth of 2½ inches it is given by the relation, $Sl/d_2=1.19$, (2) the effect of increased depth of trap seal is more pronounced with the short-turn vent fitting than with the long-turn fitting.

(3) Relative Effects of Diameter of Trap and Depth of Trap Seal. At first thought it may seem surprising that the diameter of the trap has a much greater effect on the trap-seal loss, from the standpoint of self-siphonage, than does the depth of the trap seal. However, this fact might have been predicted from inspection of the variable, $Q/d_t^2\sqrt{gt}$, which is significant in regard to the trap-seal loss. In this variable the diameter of the trap, d_t, enters as the square, while the depth of trap seal enters only as the square root and hence must have a much smaller effect than the trap diameter.

A consideration of the physics of the problem, as discussed in section 6.2, c, may make our conclusion seem somewhat more plausible. In that Section it was pointed out that the dimensionless variable, $Q/d_t^2\sqrt{gt}$, might be looked upon as the ratio of two velocities, one of which tends to empty the trap of its water seal, and the other of which tends to keep the trap filled. The first velocity is the average velocity of flow through the trap and is proportional to Q/d_t^2. The second is the velocity of free fall for a body falling through a height equal to the depth of trap seal and is proportional to $\sqrt{gt}$. Now a small reduction in d_t increases the average velocity of flow through the trap considerably and thus has a tendency to produce a considerable increase in trap-seal loss. On the other hand, a small decrease in t produces only a small decrease in the velocity of free fall and thus tends to have only a slight effect on the trap-seal loss.

As a result of the tests, the following conclusions appear to be warranted in regard to the effect on trap-seal losses of changes in diameter of trap and depth of trap seal:

1. Trap-seal losses that are due to self-siphonage are sensitive to changes in the internal diameter of the trap, and, under certain circumstances at least, will overshadow relatively large variations in depth of trap seal. The tests have shown that, in regard to the 1¼-inch trap, a relatively small decrease in internal diameter below 1¼ inches results in a marked increase in trap-seal losses.

2. Permissible unvented lengths of fixture drains are increased appreciably by increasing the seal depth from 2 to 3 inches, or higher, but primarily only because greater trap-seal losses are thus permissible.

The above discussion of the results of tests obviously offers an opportunity for the more efficient design of fixture traps.

e. Effect of Plugged Overflow

In a number of the tests the effect of plugging the overflow of the lavatory was studied in order to determine what might be the effect of preventing the aspiration of air through the overflow. Typical results are shown in figure 26. Comparison of these results with the data of figure 22, C, will show that the effect is to increase the trap-seal losses greatly. That this effect is due to preventing air from aspirating through the overflow was made obvious by tests in which a transparent trap was used. Appreciable amounts of air could be seen coming from the overflow when the latter was not closed off, and trap-seal losses were relatively small. When the overflow was closed off, this air no longer mixed with the flowing water, and the trap-seal losses increased considerably.

f. Effect of Type of Vent Fitting

It will be recalled that the lavatory test data presented earlier in this paper have all indicated that the use of a short-turn vent fitting yields smaller trap-seal losses than does a long-turn vent fitting under the same conditions of discharge. Advantage should be taken of this fact in writing

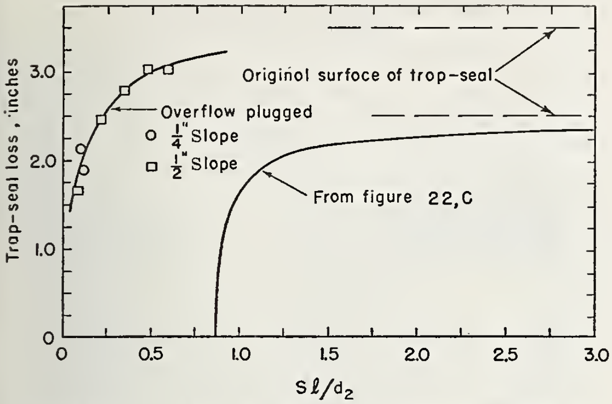

FIGURE 26. *Effect of plugged lavatory overflow on self-siphonage.*

Each point is the maximum of 10 consecutive readings. Long-turn vent fitting used. Same trap used in both series of tests, except that 1 inch was cut off leg of trap, reducing the depth of trap seal by this amount, before the tests that yielded the curve in figure 22, C, were run.

plumbing-code requirements regarding self-siphonage.

As has been stated previously, a straight-tee vent fitting was used on some of the no-trail discharge tests. Inasmuch as the relatively long depressed upper lip of the long-turn fitting has been shown to cause substantially greater losses than the straight-tee fitting, it might be expected that the small upper lip of the short-turn vent fitting would also yield greater trap-seal losses than the straight-tee fitting. However, tests made with both 1¼- and 1½-inch diameter lavatory drains [13] indicated that there was no significant difference between the two fittings in this respect, and it may be concluded that no improvement in self-siphonage characteristics would be obtained by increasing the radius of curvature of the upper lip of the short-turn vent fitting.

It is well known that the long-turn vent fitting is more effective in introducing water from a horizontal branch into a stack than is the short-turn fitting, because the former turns the water downward more than does the latter. On the other hand, the short-turn fitting has better self-siphonage characteristics than does the long-turn fitting.

Thus the characteristics of these two fittings are contradictory in these two respects. It is possible that the advantages of the two fittings could be combined in a new type of fitting in which the lower half of the cross section followed the form of the long-turn fitting, while the upper half followed the form of the straight tee fitting.

g. Effect of Rate of Fixture Discharge

From the data presented in this paper, it is obvious that the rate of fixture discharge has a marked effect on the trap-seal losses caused by self-siphonage. See figures 17, 18, 19, and 20. Thus from the standpoint of self-siphonage it is advantageous to have as low a rate of fixture discharge as is feasible. For example, figure 20 shows that with the 1½-inch cast-brass trap and 1½-inch drain, if the fixture flow is not greater than about 9 gallons per minute, the permissible unvented length of drain can be made almost indefinitely long. Similarly, for the 2-inch steel trap and drain, if the rate of flow from the fixture does not exceed about 20 gallons per minute, the same is true. Any one who is familiar with the design of plumbing systems will recognize immediately the financial savings that could result from the utilization of this fact.

In recent years the customary size of outlet orifice of the lavatory has been increased from 1⅛ to 1¼ inches. This has resulted in an increase in the rate of flow from the fixture. In 1924 Hunter [4] concluded from a series of laboratory experiments that the average rate of flow from a lavatory was 7.5 gallons per minute. Hunter did not record the dimensions of the orifices on the lavatories he tested, but tests made in this investigation have shown that this rate of discharge is closely approximated by making the diameter of the outlet orifice 1⅛ inches. However, we have found that the lavatories having a diameter of outlet orifice of 1¼ inches have an average rate of discharge of about 10 gallons per minute when the 1¼-inch trap and drain are used and about 13.2 gallons per minute when the 1½-inch trap and drain are used. Because of this it is not surprising that the permissible unvented lengths of drains found in this investigation are in some cases less than those found by Hunter [4].

Test data showing the self-siphonage produced in a fixture trap when the outlet orifice of the lavatory is 1⅛ inches and when it is 1¼ inches are shown in figure 27. In both cases the trap and drain diameters were 1¼ inches. The relatively small reduction in diameter of the outlet orifice results in an increase in the permissible unvented length of drain of approximately 100 percent.

These facts are significant, and they immediately raise the question of whether the decreased

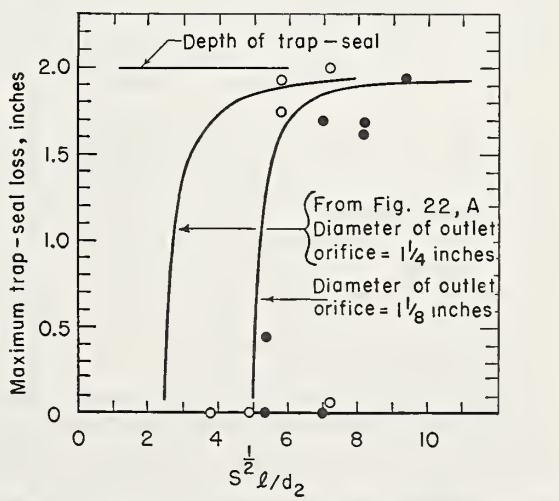

FIGURE 27. *Effect on self-siphonage of diameter of outlet orifice of lavatory.*

time of emptying the fixture caused by increasing the diameter of the outlet orifice outweighs the decreased permissible unvented length of drain and hence the increased cost of the installation. Certainly in the case of low-cost housing it does not.

7.5. Tests on Other Fixtures

The great majority of the tests made in this investigation were made with lavatories. However, other plumbing fixtures are also subject to trap-seal losses due to self-siphonage, and a few tests were made with kitchen sinks, bathtubs, and water closets. The test data on these fixtures were limited in scope, and no attempt was made to investigate systematically the self-siphonage of these fixtures. Nevertheless, the test data for sinks, bathtubs, and water closets are believed to be sufficiently extensive to indicate, in a qualitative manner at least, the relative self-siphonage effects on these fixtures.

a. Sinks

A limited number of tests were made on sinks and combination fixtures with drains 1½ inches in diameter and 8 and 10 feet in length on slopes of ¼, ½, and ¾ inch per foot. These data for a 16 by 24-inch sink are shown in table 6. The 1½-inch cast-brass trap shown in figure 28 was used in these tests. Similar tests were made on the sink compartment of the combination fixture, and the resulting trap-seal losses were in all cases smaller than those recorded in table 6.

TABLE 6. *Trap-seal losses for a 16- by 24-inch kitchen sink*

Type of strainer	Rate of discharge	Type of vent fitting	Trap-seal losses—inches: Drain length 8 feet, ¼-in. slope	½-in. slope	¾-in. slope	Drain length 10 feet, ¼-in. slope	½-in. slope	¾-in. slope
	Gpm							
Flat	16.5	Long-turn	------	------	------	0	0	0
Basket [1]	23.2	do	0	0.12	0	.75	1.00	.62
Do	23.2	Short-term	0	.50	0	.38	.75	0

[1] In these tests the basket strainer was removed from the sink.

Figures 29 and 30 show unpublished data obtained by Hunter on the self-siphonage of sinks. All of the data in these figures were obtained with drain slopes of ¼ inch per foot, except as noted. In the plotting of the data in these figures, S is the slope of the drain in inches per inch, l is the length of the drain, from the trap weir to the vent fitting in inches, and d_2 is the nominal diameter of the drain in inches.

If a remaining trap seal of 1 inch is adopted as the dividing line between satisfactory and unsatisfactory operation, the data in table 6 and figures 29 and 30 indicate that a value of Sl/d_2 of approximately 10. for the long-turn vent fitting and 1.4 for the short-turn vent fitting would serve adequately for the ordinary types of kitchen

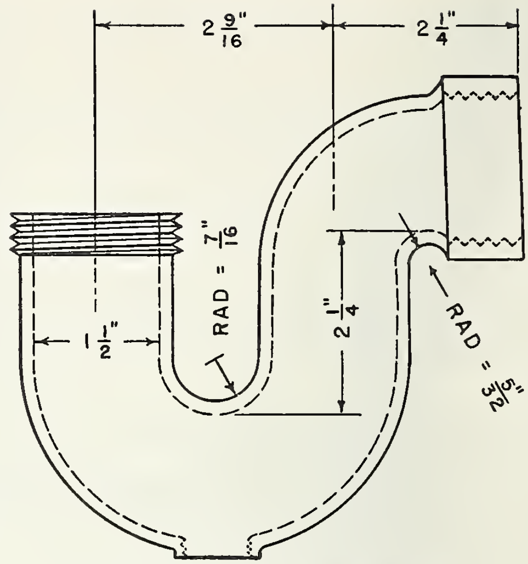

FIGURE 28. *1½-inch cast-brass trap.*

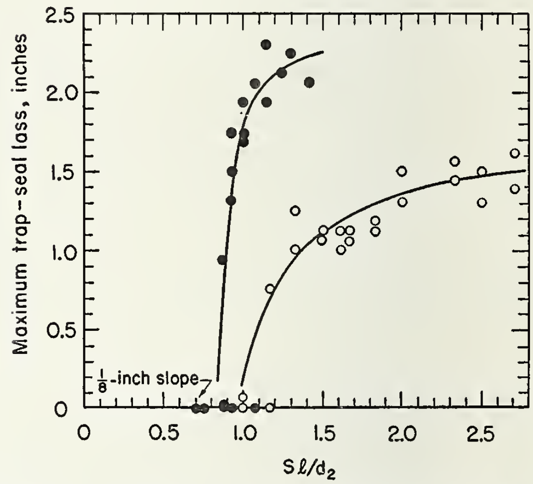

FIGURE 29. *Hunter's data on the self-siphonage of sink traps.*

Long-turn, vent fitting. ● 2-inch-diameter trap and drain. ○ 1½-inch-diameter trap and drain.

sinks and combination fixtures tested here with 1½- and 2-inch diameter drains.

b. Bathtubs

Tests were made with a conventional type of bathtub 5 feet long connected to a 1½-inch-diameter drain and trap. The tests were made with drains 17 and 25 feet long on slopes of ¼, ½, and ¾ inch per foot. In no case was any trap-seal loss noted. While these tests on one bathtub with a single type of trap cannot be considered exhaustive by any means, they do indicate that self-siphonage of bathtub traps is not a serious problem and that the permissible value of Sl/d_2 indicated earlier in this paper for commonly-used kitchen sinks and combination fixtures would provide ample safety for bathtub traps, insofar as self-siphonage is concerned.

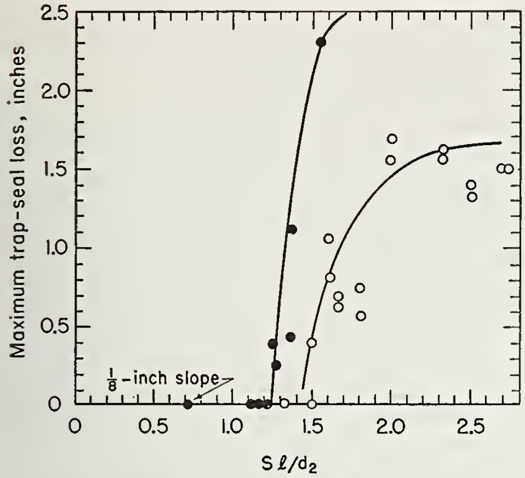

Figure 30. *Hunter's data on the self-siphonage of sink traps.*

Short-turn vent fitting. ● 2-inch-diameter trap and drain. ○ 1½-inch-diameter trap and drain.

c. Water Closets

In the preceding sections of this paper the self-siphonage of fixture traps has been viewed in the light of an undesirable phenomenon, and various methods of controlling or eliminating it have been proposed. However, in the case of a water closet, self-siphonage of the fixture is, in general, necessary for its proper operation. Hunter [14] summarizes the characteristics of an effective water closet flush as follows: "A quick priming of the siphon; a continuous siphon action for sufficient time to clear the bowl of its contents and carry them through the trapway; and a breaking of the siphon action before the flow ceases, in order to refill the trap."

The siphon action occurring in the water closet trap is "self-siphonage" in the commonly accepted meaning of the term, since it is caused by the discharge of the particular fixture connected to the trap in question, and it differs in no way from the self-siphonage of a lavatory, for example, except that in the case of the water closet the fixture trap is designed so that self-siphonage occurs during each flush of the fixture, no matter how short the drain is made, while for the lavatory, siphon action in the trap is not necessary for its proper operation and will not occur unless the drain is sufficiently long or on a sufficiently high slope, or unless one of the other variables previously mentioned as affecting self-siphonage brings it about.

As has been pointed out previously, the ill effects of self-siphonage may be overcome by increasing the volume and duration of trail discharge to the trap after the self-siphonage process has ceased. This fact is utilized in the design of water closets, and, for their proper operation, the duration and rate of discharge from the flushing device (flush valve or flush tank) must be such that sufficient water drains into the fixture from the flush valve or tank after the breaking of the siphon action in the trap to fill the latter. As Hunter has pointed out [14], the characteristic operation of conventional water-closet supply devices, if properly adjusted for volume and time, controls the rate of supply in a manner that meets this flushing requirement admirably. It is thus apparent that the self-siphonage process, far from being detrimental to the safe operation of a water closet, is necessary for its proper functioning; and specific means, consisting of an adequate amount and duration of trail discharge, have been provided by the commonly used flushing devices to overcome the usual ill effects of self-siphonage. Under these circumstances it would not be expected that the remaining trap seal in a water closet would be affected appreciably by an increase in the length or the slope of the fixture drain.

In table 7 are given self-siphonage test results obtained from the water closet set-up of figure 31. These tests were made with a 3-inch diameter drain, and the average rates of discharge were 26.1 gallons per minute with the flush tank and 30.0 gallons per minute with the flush valve. From the data in table 7 it is apparent that the trail discharge that normally refills the trap after the necessary self-siphonage process incident to the flushing action is sufficient also to prevent

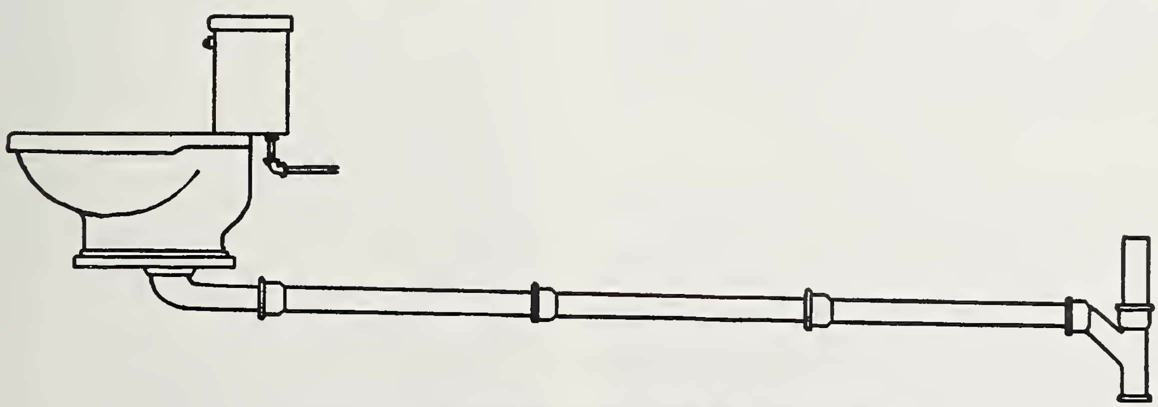

Figure 31. *Setup for self-siphonage tests of water closets.*

any appreciable trap-seal losses due to the increased slope or length of fixture drain.

Based on the data in table 7, there does not appear to be any need of limiting the unvented length of water closet drains on the score of self-siphonage.

TABLE 7. *Trap-seal losses of water closets*

Flushing device	Trap-seal losses					
	Length of drain, 5 feet		Length of drain, 20 feet		Length of drain, 25 feet	
	¼-inch slope	½-inch slope	¼-inch slope	½-inch slope	¼-inch slope	½-inch slope
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Flush tank with refill pipe in	0	0	0	0	0	0
Flush tank with refill pipe out	.38	.38	.50	.75	.38	.38
Flush valve	-------	-------	-------	-------	-------	-------

d. Miscellaneous Fixtures

In the foregoing sections of this report, self-siphonage data on the usual fixtures used in residential installations have been presented, and conclusions regarding the permissible unvented lengths of fixture drains for these fixtures have been given. However, there are many other types of fixtures used in restaurant kitchens, hospitals, and in various industrial applications that do not closely resemble those commonly found in residential installations. As has been indicated previously, the permissible unvented length of drain for such fixtures, as well as those already discussed, will depend on the rate of discharge, the length, slope, and diameter of the drain, the trap dimensions, the type of vent fitting, and the trail discharge characteristics of the fixture.

Inasmuch as the data in figures 17 to 19 were obtained under conditions of minimum trail discharge, the curves given in these figures may, for any type of fixture, be used to determine a safe unvented length of fixture drain. In this connection it may be pointed out that, while the use of figures 17 to 19 will yield safe values of the unvented length of fixture drain, it will also, for many fixtures, result in uneconomical designs, owing to the fact that the fixture drains will be limited to shorter lengths than is necessary for any fixture that has an appreciable trail discharge.

8. Conclusions

The following conclusions are believed warranted by the data presented:

1. Many variables affect the self-siphonage process. Among these are the discharge from the fixture; the length, diameter, and slope of the fixture drain; the type of vent fitting; the dimensions of the trap, particularly the depth of trap seal and the internal diameter of the trap; and the amount and duration of the trail discharge from the fixture.

2. In general, the trap-seal loss produced by the discharge of a lavatory will be about the same maximum amount if the lavatory is filled to any depth more than 3 inches.

3. Increasing the diameter of the outlet orifice of a lavatory from 1⅛ inches to 1¼ inches increases the trap-seal loss greatly, frequently more than 100 percent, owing to the increased discharge rate.

4. Flat-bottomed fixtures cause smaller trap-seal losses than do round-bottomed fixtures, owing to the greater trail discharge from the former.

5. With a 1½-inch fixture trap and drain, an 18- by 20-inch lavatory gave greater trap-seal losses than did a 20- by 24-inch lavatory, presumably owing to the greater trail discharge of the latter. When a 1¼-inch trap and drain were used, no particular difference was noted in the trap-seal losses caused by these two lavatories.

6. The elimination of the overflow in lavatories will increase the trap-seal losses substantially, see figure 26.

7. The effect on trap-seal losses of varying the vertical distance from the fixture to the trap from 6 to 12 inches appears to be negligible.

8. For a given rate of discharge from a lavatory, decreasing the diameter of the drain will increase trap-seal losses.

9. An increase in slope or a decrease in diameter of the fixture drain will tend to cause increased losses due to self-siphonage, and these two dimensions are fully as important as the length of fixture drain in causing self-siphonage.

10. Trap-seal losses are usually much greater when a long-turn vent fitting is used than when a short-turn or a straight-tee fitting is used. No significant difference between the behavior of short-turn and straight-tee fittings in this respect was observed. Thus, since it is known that a long-turn fitting is more effective in introducing water from a horizontal branch into the stack than is either the short-turn or straight-tee fitting, the characteristics of these fittings are contradictory in these respects. The fitting that is most advantageous from the standpoint of introducing the water into the stack is the least advantageous from the standpoint of self-siphonage.

11. The permissible values of $S^{1/2}l/d_2$ and Sl/d_2 given in table 2, which are based on a remaining trap seal of 1 inch, are adequate for lavatory installations throughout the plumbing system.

12. The permissible values of $S^{1/2}l/d_2$ and Sl/d_2 given in table 4, based on a remaining trap seal of ½ inch, are adequate for lavatory installations on the top floor or at other locations in the drainage system where the venting system is sufficiently underloaded or otherwise designed so that negative pressures either do not occur or are negligible in magnitude.

13. The permissible values of $S^{1/2}l/d_2$ and Sl/d_2 in tables 2 and 4 can be increased appreciably by proper choice of the lavatory trap and lavatory.

14. With short-turn vent fittings and with long-turn vent fittings when used with drains on a slope of ¼ inch per foot and less, a trap-seal loss of more than half the depth of trap seal will not

be obtained if the drain is so designed that the value of $Q/d_2^2\sqrt{gd_2}$ is less than about 0.5, see figure 18.

15. Trap-seal losses are increased if the internal diameter of a P-trap is less than that of the fixture drain. Thus, if we are to prevent excessive trap-seal losses for a P-trap due to self-siphonage, we should use a trap having a fairly large internal diameter. Furthermore, siphonage of the trap due to pressure reductions caused by the discharge of other fixtures on the system can be rendered less harmful by using a trap with a large depth of seal. While increasing the depth of seal may lead to greater trap-seal losses, it also results in a greater remaining trap seal than if a trap with a shallow seal were used.

16. If a remaining trap seal of 1 inch is adopted as the dividing line between satisfactory and unsatisfactory operation, the relation, $Sl/d_2=1.0$, when a long-turn vent fitting is used, and the relation, $Sl/d_2=1.4$, when a short-turn vent fitting is used, will give satisfactory maximum permissible unvented lengths of fixture drains for ordinary types of sinks and combination fixtures for 1½- and 2-inch diameter traps and drains, see table 6 and figures 29 and 30.

17. From limited data on bathtubs it is concluded that the permissible values of Sl/d_2 given for sinks can be applied with at least equal safety to bathtubs. It is believed that more extensive data on the self-siphonage characteristics of bathtub traps will indicate that self-siphonage of this fixture is not serious under any commonly used method of installation, and that the permissible values of Sl/d_2 suggested here can be increased with ample safety.

18. The test results on the self-siphonage of water closets have indicated that the unvented length of drain for these fixtures need not be limited because of self-siphonage.

19. Permissible unvented lengths of drains for fixtures for which specific data are lacking can be obtained from figures 17 to 19, inclusive. The permissible unvented lengths of drain obtained in this manner will be safe, but, for most fixtures, and especially for those with appreciable trail discharge, the data in figures 17 to 19 will yield drain lengths considerably shorter than those that might be used with complete safety.

20. Standardization of the dimensions of fixture traps, and especially of lavatory traps, with regard to internal diameter and depth of trap seal is highly desirable. Minor restrictions on these dimensions can lead to substantially increased unvented lengths of fixture drains.

21. Standardization of the hydraulic characteristics of fixtures is desirable, at least for lavatories, sinks, and combination fixtures. Substantially increased permissible unvented lengths of fixture drains can be obtained for a moderate decrease in the discharge rates of the fixtures.

22. Increase in depth of trap seal above the 2-inch minimum commonly permitted by codes will make it possible to increase appreciably the maximum permissible unvented lengths of fixture drains.

23. It is practically impossible to duplicate results in self-siphonage tests owing to the fact that conditions in the fixture drain are rarely twice alike, even when the tests are conducted under the most carefully controlled conditions. All that can be expected is that the range of values obtained in a series of tests under conditions that are as nearly identical as it is possible to make them can be repeated approximately.

9. Considerations Regarding the Self-Siphonage Problem

Most plumbing codes provide protection against trap-seal losses due to fixture self-siphonage solely by limiting the length of the unvented portion of the fixture drain; that is, they limit the distance between the trap weir and the vent fitting. The data presented in this paper show clearly that there are several other variables involved that exert an equally important effect on the trap-seal losses due to self-siphonage.

The rate of discharge from the fixture, the slope and diameter of the fixture drain, the type of vent fitting, and the dimensions of the trap have been shown to be of primary importance likewise. The rate of discharge from such fixtures as lavatories and sinks is controlled in large measure by the diameter and other physical characteristics of the outlet orifice, and, in the case of the lavatory, self-siphonage is so sensitive to outlet orifice conditions that appreciable differences in trap-seal losses may sometimes be observed with fixtures of the same manufacture and model number, these fixtures being identical in every respect except for small differences in the bevel provided on the outlet orifice to accommodate the rubber stopper.

An increase in the slope of the fixture drain or a decrease in its diameter will cause increased trap-seal losses due to self-siphonage, and these two dimensions are fully as important in controlling self-siphonage as the length of the drain.

The permissible unvented length of drain is affected to an important degree by the type of vent fitting connecting the drain to the continuous waste and vent or to the stack, and under certain conditions the permissible unvented length of drain for the short-turn fitting may be more than twice that for the long-turn fitting.

The data presented have shown that the trap-seal losses due to self-siphonage are very sensitive to small variations in the internal diameter of the trap, and that a relatively small decrease in trap diameter may cause a substantial increase in trap-seal losses. Although trap-seal losses due to self-siphonage, and consequently permissible unvented lengths of fixture drains, are not as sensitive to changes in depth of trap seal as to changes in trap diameter, it has been shown nevertheless that substantial increases in depth of trap seal above the 2-inch minimum commonly permitted by codes will provide an appreciably increased permissible unvented length of drain through the fact that such an increase in trap-seal depth makes possible an increased permissible seal loss.

In like manner, lavatories, as well as other fixtures, are made in a variety of sizes and forms. Tests on the 18- by 20-inch lavatory have shown it to have, under certain conditions, worse self-siphonage characteristics than the 20- by 24-inch lavatory, owing undoubtedly to its smaller surface area and consequently shorter period of trail discharge.

Under these conditions it is not surprising that current plumbing codes show a lack of uniformity as regards permissible unvented lengths of fixture drains, for, in view of the above discussion, it obviously could not be expected that tests made in one place would yield results as to the permissible unvented lengths of fixture drains that would be comparable with test results obtained at another place, unless care were taken to insure that the traps, fixtures, vent fittings, and other variables entering the problem had been properly considered.

Because of the many variables connected with the problem of self-siphonage, and in view of their effect on permissible unvented lengths of fixture drains, it is obviously impossible, with the present wide diversity in the design of lavoratories (and other fixtures) and traps, and with the present lack of uniformity in the use of the two types of vent fittings, to establish a single and simple limit on the permissible unvented length of drain which will be equally safe and equally economical for all installations. Until such time as installation procedure and the hydraulic characteristics of fixtures and traps are standardized, plumbing codes must either provide rather complicated requirements regarding self-siphonage, by permitting different unvented lengths of drain for different types of lavoratories (and other fixtures), traps, and vent fittings, or they may provide a single, simple restriction on unvented lengths of fixture drains, which is unduly conservative for the majority of the installations and in many instances uneconomical.

In the analysis of the results of this investigation a relatively large safety factor has been introduced. This was accomplished in four ways. First, a remaining trap-seal requirement of 1 inch was adopted, which means that after the trap has been siphoned, it will be able to resist pressure fluctuations in the drainage system twice as large as those for which the venting system is ordinarily designed. Second, in applying the remaining trap-seal requirement, the least remaining trap seal observed in 10 identical tests was used. Third, with special reference to the lavoratory tests, the traps selected for use in this investigation were those which gave the worst results of all the traps that were on hand for the investigation. And finally the tests were made by filling the lavatories to their overflows.

The result is that the recommendations made in this paper as to the maximum permissible unvented lengths of drain are, in our judgment, extremely conservative and may be used with complete safety by code-writing authorities. As a consequence, it is not necessary to adhere rigidly to the exact values suggested for these lengths.

In connection with this question of safety factor involved in the recommendations made here, it may be pointed out that approximately 25 years ago, when a minimum remaining trap seal of 1 inch was first suggested, allowance was made for the effect of fouling of the fixture drains. The Uniform Plumbing Code Committee did the same thing, yet this fact seems to have been forgotten. It is true that we do not as yet have any reliable data as to the effect on self-siphonage of fouling of the fixture drain, and so we cannot set any upper limit to this effect. On the other hand, the dangers of an occasional loss of trap seal have been greatly exaggerated. The odor of sewer gas (or probably it would be better to say sewer air) may be offensive, but according to public health authorities, the sewer air is not dangerous or detrimental to the health unless present in great concentration or continuously over a considerable period of time, a condition that is unlikely to occur in a building as the result of a lost trap seal, except perhaps in the case of a floor drain. Probably the function of the water seal is actually more to prevent the development of a nuisance condition than to protect the health, contrary to what many believe.

The purpose of this investigation has been twofold. The first and most important object was to determine the factors that affect fixture self-siphonage and to suggest means of minimizing the ill effects of this phenomenon. The second purpose of the paper was to suggest permissible unvented lengths of fixture drains based on the experimental work of the investigation. The latter objective, as has been seen, involved the adoption of a minimum requirement for the remaining trap seal.

The point of view adopted in this paper with regard to the relationship between remaining trap seal and permissible unvented length of fixture drain is the one commonly held at present. That is to say, since the publication in 1924 of Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings [3], it has been considered good practice to require a minimum remaining trap seal of 1 inch after self-siphonage has occurred. Although the authors in interpreting the test data have adhered to this criterion of good practice (except as noted in the paper for underloaded venting systems), they wish to point out nevertheless that this requirement is entirely arbitrary, and in their considered judgment it will eventually be reduced. The authors, in considering this question of what constitutes a reasonable requirement for remaining trap seals, have been handicapped because the problem is not such that it can be investigated by experimental means or by any simple analysis.

In view of the fact that the principal factors influencing the establishment of a reasonable requirement for remaining trap seals are the magnitude and frequency of the pressure fluctuations in the drainage system, considered together with the frequency and magnitude of trap-seal losses and their duration, it is apparent that the problem may be attacked in either of two ways. First, the problem is amenable to solution through extensive and systematic field investigations, and secondly the problem may be attacked through probability considerations, together with a limited field investigation. The latter method would require an investigation of the probability of a positive pressure equal in magnitude to twice the remaining trap seal occurring at the same time as the remaining trap seal in question.

In view of the magnitude of the analysis and field investigation required to establish a rational requirement as to remaining trap-seals, the writers had no alternative but to interpret the experimental data on the basis of requiring a 1-inch remaining trap-seal in accordance with commonly accepted good practice, and to defer for the present their investigation of this important aspect of the self-siphonage phenomenon. It is hoped that it will be possible to consider this latter phase of the self-siphonage problem in a future paper.

Industry can play an important part in reducing the cost of plumbing, if it can be persuaded to adopt standard designs for fixtures that will impose smaller demand and drainage loads on the system. And if, in addition industry can be induced to standardize fixture traps, adopting a design or designs that are less subject to self-siphonage than many of the traps in use today, very decided modifications can be made in plumbing codes to allow for this, with resultant economies in the construction of plumbing systems.

Suggestions have been made in this paper which make it possible for definite improvements from the standpoint of self-siphonage to be made in the design of fittings, fixtures, and traps. The authors hope that these suggestions will ultimately make it possible to improve the design of the items mentioned.

10. Importance of Economy in the Use of Water

One other matter might be mentioned here. The increasing number of instances of water shortage make it imperative that all possible economies in the use of water be given prompt consideration. Hence immediate consideration should be given to possibilities of reducing the use of water in plumbing fixtures. There are two ways in which such economies can be achieved, first, by reducing the amount of water involved in each use of a fixture; and second, by changing the habits of the public as regards the use of plumbing fixtures. It would seem obvious that the second way suggested can be made effective only by a concerted process of education extending over a long period of years.

The first way proposed is largely in the hands of the plumbing industry, and this, too, would involve an uphill fight, since the convenience of the public is in conflict with the attainment of economy. The water closet is one fixture, however, in which economy of operation might be achieved without encountering resistance from the public, since the amount of water used per flush is automatically controlled. If a water closet and flushing device should be designed to operate effectively with one gallon of water less per flush than is now required, the savings might be estimated conservatively at 20 gallons per day per household. In a large city such a saving would be very considerable.

That there is a real possibility of reducing the amount of water used in each flush of a toilet bowl was shown some years ago by Camp [15]. He demonstrated that some water closets, at least, could be flushed properly with 3 gallons of water, whereas 4 or more gallons is generally used today.

Acknowledgment is made to the Housing and Home Finance Agency for its support of the investigation reported in this paper. The authors also wish to express their appreciation of the cooperation of the members of the Uniform Plumbing Code Committee, and especially that of the Chairman, Vincent T. Manas, in formulating the problem investigated and in offering practical suggestions.

The authors also express their appreciation for the many valuable suggestions made by Edward Monteath, who acted as Industrial Adviser to the Bureau in connection with the investigation. The experimental work was carried out by Robert S. Wyly, Marion R. Brockman, Anthony L. Lembeck, Victor Brame, Jr., Richard J. O'Brien, and Edward J. Norcome, and the authors are indebted to them for their careful and thorough work.

11. References

[1] John L. French, Stack venting of plumbing fixtures, NBS Building Materials and Structures Report BMS118 (1950).

[2] John L. French, Herbert N. Eaton, and Robert S. Wyly, Wet Venting of plumbing fixtures, NBS Building Materials and Structures Report BMS119 (1950).

[3] A. E. Hansen, Plumbing fixture traps; a historical and engineering research on vented and unvented traps. (1921).

[4] Recommended minimum requirements for plumbing in dwellings and similar buildings, Elimination of Waste Series, BH2, National Bureau of Standards (1924).

[5] F. M. Dawson and A. A. Kalinske, Report on the hydraulics and pneumatics of the plumbing drainage system; Technical Bulletin No. 2, National Association of Master Plumbers (1939).

[6] Harold E. Babbitt, Tests on the hydraulics and pneumatics of house plumbing, Engineering Experiment Station Bulletin No. 143, University of Illinois (1924).

[7] Harold E. Babbitt, Tests on the hydraulics and pneumatics of house plumbing, Part II; Engineering Experiment Station Bulletin No. 178, University of Illinois (1928).

[8] Edgar Buckingham, Model experiments and the form of empirical equations. Transactions American Society of Mechanical Engineers, vol. 37, page 263 (1915).

[9] P. W. Bridgman, Dimensional analysis, Yale Univ. Press, New Haven, Conn. (1931).

[10] Garrett Birkhoff, Hydrodynamics, Princeton University Press for University of Cincinnati (1950).

[11] Report of the Uniform Plumbing Code Committee, U. S. Government Printing Office, July 1949.

[12] Plumbing Manual, NBS Building Materials and Structures Report BMS66 (1940).

[13] Investigation of the self-siphonage of lavatory traps. Report VI/6- 6651.60, National Bureau of Standards (unpublished). Issued to the Public Housing Authority (1945).

[14] Roy B. Hunter, Methods of estimating loads in plumbing systems; NBS Building Materials and Structures Report BMS65 (1940).

[15] Thomas R. Camp, The hydraulics of water closet bowls and flushing devices: Massachusetts State Association of Master Plumbers and the Massachusetts Institute of Technology (1936).

WASHINGTON, January 10, 1951.

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page II]

*Out of print.

[List continued on cover page IV]

BUILDING MATERIALS AND STRUCTURES REPORTS

[Continued from cover page III]

BMS82	Water Permeability of Walls Built of Masonry Units	25¢
BMS83	Strength of Sleeve Joints in Copper Tubing Made With Various Lead-Base Solders	15¢
BMS84	Survey of Roofing Materials in the South Central States	15¢
BMS85	Dimensional Changes of Floor Coverings With Changes in Relative Humidity and Temperature	10¢
BMS86	Structural, Heat-Transfer, and Water-Permeability Properties of "Speedbrik" Wall Construction Sponsored by the General Shale Products Corporation	15¢
BMS87	A Method for Developing Specifications for Building Construction—Report of Subcommittee on Specifications of the Central Housing Committee on Research, Design, and Construction	20¢
BMS88	Recommended Building Code Requirements for New Dwelling Construction With Special Reference to War Housing	*
BMS89	Structural Properties of "Precision-Built, Jr." (Second Construction) Prefabricated Wood-Frame Wall Construction Sponsored by the Homasote Co	15¢
BMS90	Structural Properties of "PHC" Prefabricated Wood-Frame Constructions for Walls, Floors, and Roofs Sponsored by the PHC Housing Corporation	15¢
BMS91	A Glossary of Housing Terms	15¢
BMS92	Fire-Resistance Classifications of Building Constructions	30¢
BMS93	Accumulation of Moisture in Walls of Frame Construction During Winter Exposure	10¢
BMS94	Water Permeability and Weathering Resistance of Stucco-Faced, Gunite-Faced, and "Knap Concrete-Unit" Walls	15¢
BMS95	Tests of Cement-Water Paints and Other Waterproofings for Unit-Masonry Walls	25¢
BMS96	Properties of a Porous Concrete of Cement and Uniform-Sized Gravel	10¢
BMS97	Experimental Dry-Wall Construction With Fiber Insulating Board	10¢
BMS98	Physical Properties of Terrazzo Aggregates	15¢
BMS99	Structural and Heat-Transfer Properties of "Multiple Box-Girder Plywood Panels" for Walls, Floors, and Roofs	15¢
BMS100	Relative Slipperiness of Floor and Deck Surfaces	10¢
BMS101	Strength and Resistance to Corrosion of Ties for Cavity Walls	10¢
BMS102	Painting Steel	10¢
BMS103	Measurements of Heat Losses From Slab Floors	15¢
BMS104	Structural Properties of Prefabricated Plywood Lightweight Constructions for Walls, Partitions, Floors, and Roofs Sponsored by the Douglas Fir Plywood Association	30¢
BMS105	Paint Manual With Particular Reference to Federal Specifications	$1. 25
BMS106	Laboratory Observations of Condensation in Wall Specimens	*
BMS107	Building Code Requirements for New Dwelling Construction	*
BMS108	Temperature Distribution in a Test Bungalow With Various Heating Devices	15¢
BMS109	Strength of Houses: Application of Engineering Principles to Structural Design	$1. 50
BMS110	Paints for Exterior Masonry Walls	15¢
BMS111	Performance of a Coal-Fired Boiler Converted to Oil	15¢
BMS112	Properties of Some Lightweight-Aggregate Concretes With and Without an Air-entraining Admixture	10¢
BMS113	Fire Resistance of Structural Clay Tile Partitions	15¢
BMS114	Temperature in a Test Bungalow With Some Radiant and Jacketed Space Heaters	25¢
BMS115	A Study of a Baseboard Convector Heating System in a Test Bungalow	15¢
BMS116	Preparation and Revision of Building Codes	15¢
BMS117	Fire Resistance of Walls of Lightweight Aggregate Concrete Masonry Units	20¢
BMS118	Stack Venting of Plumbing Fixtures	15¢
BMS119	Wet Venting of Plumbing Fixtures	20¢
BMS120	Fire Resistance of Walls of Gravel-Aggregate Concrete Masonry Units	15¢
BMS121	Investigation of Failures of White-Coat Plasters	25¢
BMS122	Physical Properties of Some Samples of Asbestos-Cement Siding	15¢
BMS123	Fire Tests of Wood-Framed Walls and Partitions With Asbestos-Cement Facings	15¢
BMS124	Fire Tests of Steel Columns Protected With Siliceous Aggregate Concrete	15¢
BMS125	Stone Exposure Test Wall	30¢
BMS126	The Self-Siphonage of Fixture Traps	20¢

*Out of print.