Stack Venting of Plumbing Fixtures

United States Department of Commerce
National Bureau of Standards
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Stack Venting of Plumbing Fixtures

by John L. French

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Foreword

Ever since the formation of the Department of Commerce Building Code Committee in 1921, investigations of the various fundamental problems relating to the physics of flow in the water-supply and sanitary drainage systems of buildings have been in progress at the National Bureau of Standards. These investigations have resulted in part or in whole in the publication of the following papers:

"Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings," Final Report of the Subcommittee on Plumbing of the Building Code Committee, BH2, 1924;

"Recommended Minimum Requirements for Plumbing," Report of Subcommittee on Plumbing of the Building Code Committee, BH13, 1928 (revised 1931);

"Cross-Connections in Plumbing Systems," Research Paper RP1086, 1938;

"Backflow Prevention in Over-Rim Water Supplies," Building Materials and Structures Report BMS28, 1939;

"Methods of Estimating Loads in Plumbing Systems," Building Materials and Structures Report BMS65, 1940;

"Plumbing Manual," Building Materials and Structures Report BMS66, 1940;

"Water-Distributing Systems for Buildings," Building Materials and Structures Report BMS79, 1941.

Investigations of plumbing systems were almost completely suspended at this Bureau during the recent war but have been resumed during the past two years, largely owing to the sponsorship of research projects by the Housing and Home Finance Agency as part of a comprehensive research program which is being sponsored by that Agency as a part of their program under their statutory authority. The specific problems studied in these recent investigations comprise part of this program and include stack venting, wet venting, the self-siphonage of fixture traps, and the capacities of vertical building stacks and horizontal branches.

The present report relates to a particular type of venting; namely, stack venting, which can be used satisfactorily under certain restricted conditions and which makes possible appreciable economies in the construction of building drainage systems. The experimental data presented here afford a sound foundation on which code-writing authorities can base plumbing code requirements relating to stack venting.

E. U. Condon, *Director.*

Stack Venting of Plumbing Fixtures

by John L. French

This report describes the methods used and the results obtained in an investigation of the adequacy of stack venting a group of plumbing fixtures on the top floor of a building. Trap-seal losses of stack-vented fixtures in an experimental installation are reported, a test loading having a reasonable probability of occurrence is developed, and a criterion of satisfactory trap-seal loss is proposed. The experimental results are interpreted in the light of the adopted test loading and the adopted permissible trap-seal loss. And, finally, conclusions in a form suitable for the use of code-writing authorities are made.

CONTENTS

I. Introduction

There is general agreement that the flow of sewer gas from the plumbing drainage system into a dwelling in appreciable amounts is undesirable and under some circumstances may even be dangerous. To prevent this flow of sewer gas or air into the dwelling, traps containing a liquid seal are almost universally installed on plumbing fixtures. The flow of water-carried wastes in a plumbing drainage system creates positive and negative pressures (measured from the prevailing atmospheric pressure) in various parts of the system. In order that fixture trap seals may not be endangered, vent pipes leading to the atmosphere are installed to prevent excessive pressure fluctuations.

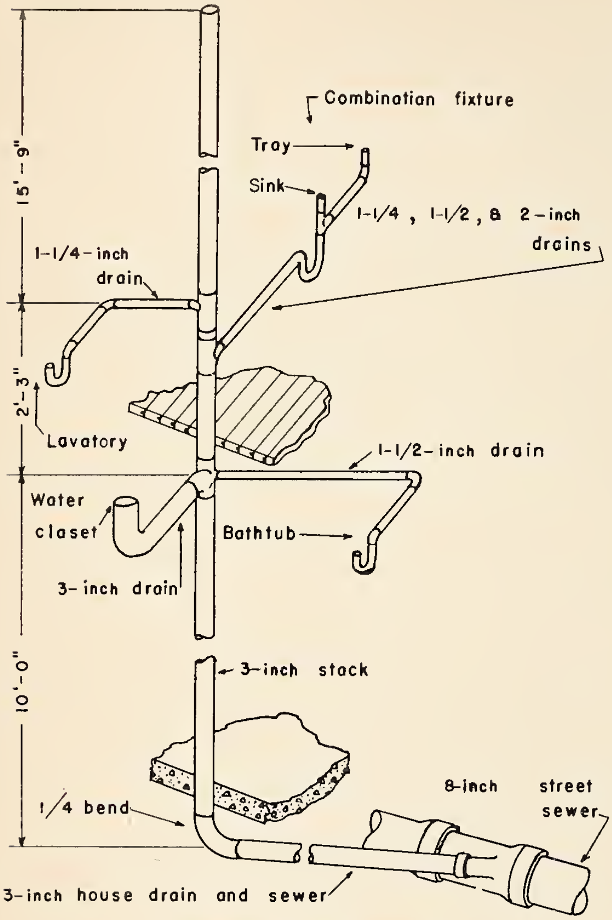

FIGURE 1. *Test system.*

The pressure fluctuations acting on the liquid seal of a trap may for convenience be divided into two classes; those caused by the discharge of the fixture to which the trap is connected, and those caused by the discharge of other fixtures connected to the drainage system. The type of venting known as stack venting, in which the drains of the fixtures on one floor level connect independently to the stack without any venting other than that secured through the stack and stack vent, is a method of drainage-system design in which the detrimental effects of pressure fluctuations due to the second cause mentioned above are reduced or overcome by (1) limiting the load on the stack above the stack-vented fixtures and (2) connecting the stack-vented fixtures to the stack at points where the fluctuations above and below atmospheric pressure are small.

Figure 1 shows a group of stack-vented fixtures on the top floor of a building. The drains from the lavatory and the combination fixture connect to the stack above the water-closet and bathtub drains. The drains from the water closet and bathtub both connect into the stack at the same level just below the floor. While all of these fixtures can be called "stack-vented," it is only the water-closet and the bathtub traps, as will be seen from the test data to be presented later, that cause concern in connection with stack venting. In the case of the lavatory there is no flow in the stack past the lavatory drain, and this fixture is, in effect, back-vented. The flow in the stack past the combination-fixture drain consists only of the discharge from the lavatory, and this flow is so small that no trap-seal loss occurs. However, in the case of the water closet and tub, the flow in the stack past their drains may consist of the discharge of both the combination fixture and lavatory, and this flow may be sufficiently large to cause seal losses in the traps of the water closet and bathtub.

Stack venting of plumbing fixtures affords, under certain conditions, a simplification of the drainage and venting system, which leads to a lowering of construction costs and, according to some investigators, to better venting. The purpose of this paper is to present the results of an experimental investigation of the merits of stack venting.

The experimental procedure used in the investigation was designed to answer in a simple and straightforward manner the practical question as to the permissibility and safety of using stack-vented plumbing drainage systems. The tests were not designed to investigate the more fundamental and complicated, but closely allied, problem of pneumatic stack pressures immediately below the point of water entrance to the stack.

II. Statement of the Problem

When the upper of two stack-vented fixtures, such as are shown in figure 2, is discharged, the lower fixture will lose part of its seal under certain conditions. All of the details of the physical process by which the loss in trap seal occurs have not been studied. However, it appears certain that the principal cause of the seal losses in the lower fixture trap is the negative pressure created in the stack by the discharge of the upper fixture. Dawson and Kalinske [1] [1] have investigated this problem experimentally, and some of their results are shown in figure 3. Other factors possibly affecting to some extent the amount of trap-seal loss of the lower fixture might include the thickness and the velocity of the sheet of water in the stack flowing past the drain of the lower fixture and the

[1] Numbers in brackets indicate references at the end of the paper.

diameter of the drain of the lower fixture. The effect of these latter factors is believed to be relatively small, but they may account, at least in part, for some of the differences in the test results obtained with a 1½-inch bathtub drain and a 3-inch water-closet drain connected to the stack at the same level, where the negative pressure in the stack can be assumed to be the same for both fixture drains.

Other factors, which will be shown in test results to be presented in this paper to affect the trap-seal losses of the lower fixture in figure 2 when the upper fixture is discharged, include the length and slope of the lower fixture drain and the depth of the seal and the diameter of the lower trap.

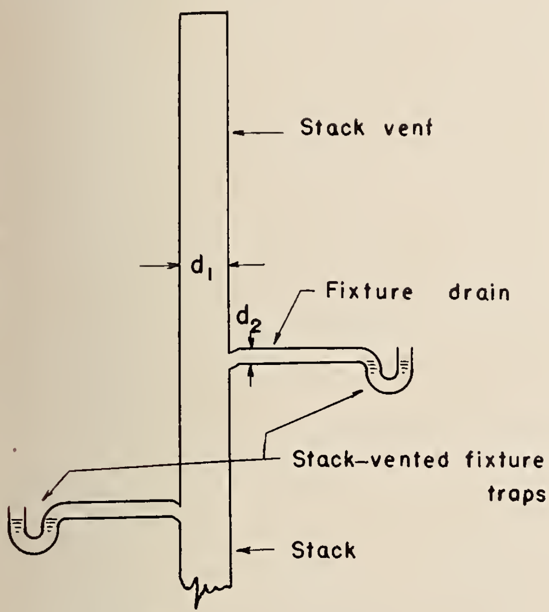

FIGURE 2. *Stack-vented fixture traps.*

It will be noted from Dawson and Kalinske's data in figure 3 that the negative pressure in a stack at a distance z below the point of water entrance varies with z, and with the volume rate of inflow, Q. Since the trap-seal loss of a stack-vented fixture trap is dependent on the negative pressure in the stack, among other things, it follows that the trap-seal losses of stack-vented-fixture traps will also vary with z and with Q.

The problem of this investigation is to determine the restrictions that must be placed on Q in terms of fixture discharge, and the limitations, if any, that must be placed on z, in order that the fixtures of a single bathroom and kitchen on the top floor of a system may be connected directly to the

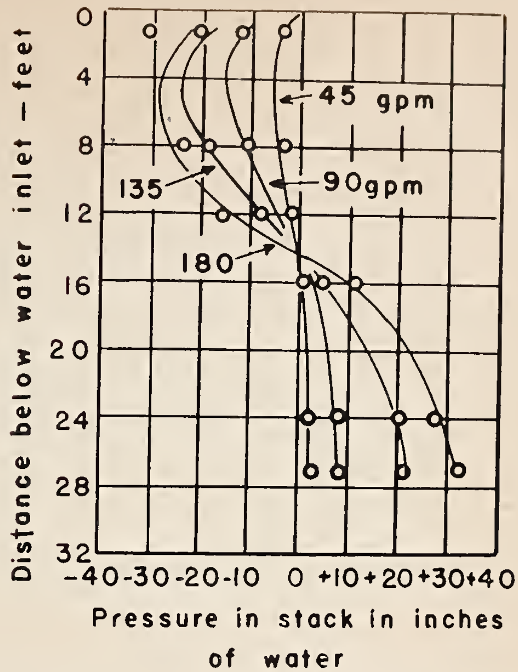

FIGURE 3. *Variation of air pressure in 3-inch stack below point of water entrance.*

vertical stack without any venting other than that provided by the stack vent.

The terms "depth of seal" and "trap-seal loss" will be used frequently in this paper. These terms refer to the dimensions shown in figure 4.

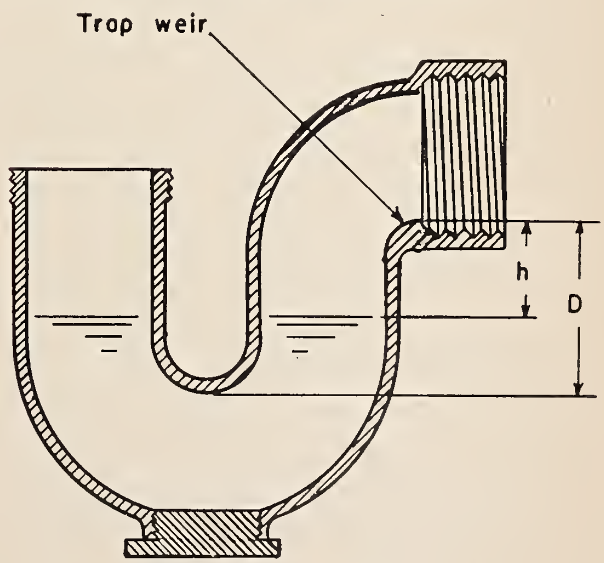

FIGURE 4. *Definition sketch of trap.*

h=trap-seal loss. D=depth of trap seal.

III. Previous Consideration of the Problem

The economies that are made possible through the stack venting of fixtures have been recognized for a number of years, and several experimental investigations have been made of the merits of this type of venting. However, these investigations for the most part have been made as minor parts of the study of a broader problem, and consequently the detailed test data, other than conclusions, have either not been reported, or the data reported have either been inconclusive or possibly not entirely applicable to systems subjected to the higher rates of flow of some modern fixtures.

Perhaps the most detailed investigation of stack venting was made by Hunter [2], who concluded from tests on a 3-inch-diameter stack: "With this layout (a stack-vented water closet, bathtub, lavatory, and kitchen sink on the top floor of a plumbing drainage system) no measurable loss of seal was produced in any trap of the group by any combination or order of discharge of the fixtures of the group itself, or in conjunction with other fixtures lower on the stack." These tests were made over 25 years ago, and certain fixtures, particularly lavatories, kitchen sinks, and combination fixtures, have been modified since that time so as to increase their rate of flow materially. As the magnitude of the trap-seal loss of a stack-vented fixture will depend on, among other variables, the rate of flow from fixtures on the stack above the fixture in question, it follows that the conclusions expressed by Hunter may not be valid for fixtures in common use today.

Babbitt [3] and Dawson and Kalinske [4] have also concluded that under certain conditions the stack venting of top-floor fixtures is satisfactory.

The most recent investigation of the conditions under which the stack-venting of fixtures is permissible is that reported by the Plumbing Committee of the Building Research Board of the Department of Scientific and Industrial Research [5]. In this investigation, both one- and two-story installations were tested with all fixtures stack-vented. The Committee concluded that:

"a. Simple one-pipe systems for one- and two-story housing can be designed to operate under practical conditions of use without siphonage of traps in spite of the absence of special trap ventilation" (i. e., back vents).

"b. The size of stacks and branches has a controlling influence on the liability to siphonage, the use of 4-inch stacks with 2-inch branches giving safer conditions than obtain with smaller stacks and branches."

Unfortunately, the report of the Committee does not describe in detail the fixtures used and, in particular, does not give the rate of discharge from the fixtures.

In addition to these direct studies of the merits of the stack venting of top-floor fixtures, Dawson and Kalinske [1] have made a rather extensive investigation of the pressure below a point of water entrance in a stack without vents of any kind except a stack vent. These tests were made by introducing different rates of flow into a stack through a horizontal branch or fixture drain connected to the stack by a sanitary **T** fitting, and then observing the pressures in the stack at various distances below the point of water entrance.

As the trap-seal losses experienced by a stack-vented fixture, owing to the discharge of a fixture higher on the stack, must be a function, among other things, of the negative pressure in the stack at the point where the drain of the stack-vented fixture connects to the stack, it is obvious that Dawson's and Kalinske's data are significant as regards the conditions under which stack venting of fixtures is permissible. For example, these data show that, if the rate of flow from the higher fixtures on the stack and if the vertical distance between the upper and lower stack-vented fixtures are sufficiently limited, the pressure reductions in the stack can be made as low as desired; and hence it is apparent, with suitable restrictions regarding the location and rates of fixture discharge, that adequate protection of fixture traps can be secured by stack venting. Although the data of Dawson and Kalinske are significant in a qualitative manner as regards the problem of stack venting and will be found useful in analyzing some of the test results of the present investigation, they cannot be used to predict quantitatively the trap-seal losses that will occur with stack-vented fixtures because (1) the particular rates of flow down a stack to which stack-vented fixtures are subjected were not treated in detail, and (2) the diameter of the drain introducing water to the stack was in general of the same diameter as the stack, while in the case of stack-vented fixtures the upper fixtures have drains of smaller diameter than the stack. As will be shown later, these factors greatly affect the trap-seal losses of stack-vented fixtures, and also, presumably, the pressures in the stack near the point of water entrance.

IV. Description of Test System

The test system is shown in figure 1. The stack and building drain were made of transparent methacrylate plastic tubing 3 inches in diameter. The building sewer was constructed of 3-inch-diameter cast-iron soil pipe and was connected to an 8-inch-diameter vitrified-clay street sewer.

The rate of flow in the street sewer could be varied at will up to 300 gallons per minute.

The traps and drainage fittings used were, in general, made of transparent plastic material. However, many of the tests were made with a conventional metal trap and metal drain connected to the combination fixture and with a metal drainage fitting connecting this fixture drain to the stack. The tests made with the transparent drains and stacks were helpful in visualizing the physical phenomena involved in the flow.

The fixtures used were of current manufacture and were selected to give a loading on the test system that would be representative of those to be found on similar systems in service.

The water closet used was of the tank-operated, siphon-jet type. Its average rate of discharge was 26.1 gallons per minute. The volume of discharge was 8.0 gallons, which is greater than that of most water closets in common use. The bathtub used was of standard design, 5 feet long, equipped with a 1½-inch trap and drain. The average rate of flow from the tub when filled to a depth of 6 inches was 12.4 gallons per minute.

A 20 by 24-inch lavatory with a 1¼-inch outlet orifice was used on the system. The lavatory was connected to the stack by a 1¼-inch trap and drain. The average rate of flow from the lavatory was 11.1 gallons per minute.

The combination fixture used on the system was the typical fixture with a separate sink and laundry-tray compartment. The trap was located directly under the outlet orifice of the sink compartment. The tray compartment was 17½ inches wide by 18¼ inches long by 13 inches deep. The sink compartment was of the same dimensions, except that the depth was 8 inches. The dimensions given are for the top of the combination fixture. The bottom areas of both the sink and the tray compartments were slightly less. The tray compartment was equipped with a metal drain plug with a cross-bar strainer and rubber stopper. The diameter of the tray outlet orifice was 1 19/32 inches. The sink compartment was equipped with a removable basket-type strainer.

The average rate of flow from the sink compartment varied from 30 to 41 gallons per minute, depending on the type of fixture trap, the length, slope, and diameter of the waste, and on the vertical distance between the trap and the sink. The average rate of flow from the fixture when the sink and tray compartment were discharged simultaneously varied from 30 to 45 gallons per minute.

The rates of flow given are average rates obtained by measuring the volume of water in the fixture and then observing the time required for the fixture to empty. In the case of the combined rate of discharge from the sink and tray compartments of the combination fixture, the problem was slightly more complicated, inasmuch as the sink compartment empties more quickly than the tray compartment. In this case both compartments were filled with water, and the time required for the sink compartment to empty was noted. At the end of the period of discharge from the sink, the height of the water level in the tray compartment was observed. In this manner the total volume of water discharged from the combination fixture during the period of flow from the sink was obtained, and the average rate of flow was, of course, this volume divided by the time required for the sink compartment to empty.

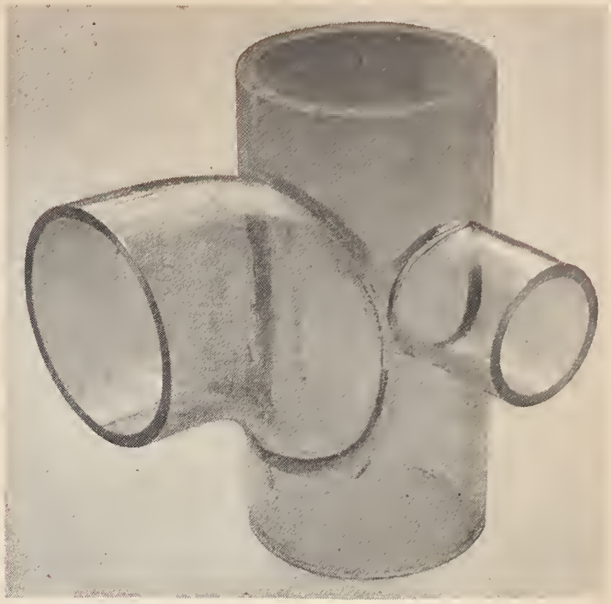

FIGURE 5. *Transparent plastic stack fitting.*

The diameters of the lavatory drain, bathtub drain, and watercloset drain were, respectively, 1¼, 1½, and 3 inches for all the tests. On most of the tests the diameter of the combination fixture drain was 1½ inches, but a few tests were also made with this drain 1¼ and 2 inches in diameter.

The water-closet and bathtub drains were connected to the 3-inch-diameter stack by means of a plastic sanitary fitting with a 1½-inch side inlet. This fitting is shown in figure 5. The lavatory connected to the stack through a sanitary fitting. Most of the tests were made with the combination-fixture drain connecting to the stack through a sanitary fitting, but some of the tests were also made with a long-turn T-Y at this point.

V. Test Procedure

The tests were made by discharging certain of the fixtures attached to the stack and then observing the trap-seal losses or other pertinent behavior of all the traps.

The lavatory was filled completely to the overflow level and was then discharged by pulling the rubber plug from the outlet orifice. The sink and tray compartments of the combination fixture were filled to a point approximately 1 inch below their overflow rims. The sink compartment was discharged by pulling the basket-type strainer completely out of the sink. The tray compartment was discharged by pulling the rubber stopper out of the outlet orifice.

For reasons to be given shortly, it was not necessary to discharge either the water closet or bathtub in most of the tests. In the few tests in which these fixtures were discharged, the water closet was discharged in the usual manner, and the tub was filled to a depth of 6 inches and was discharged by pulling the rubber stopper from the outlet orifice.

VI. Test Results

There are three ways in which a plumbing drainage system, subjected to a given test loading, can fail to function properly. First, the system may be designed in such a manner, or the test loading imposed on the system may be such, that sluggish drainage of some of the fixtures may result. A failure of this nature implies a relatively high pressure in the fixture drain, and, as would be expected, none of the tests on the single-story stack-vented system indicated failure of the system from this cause. Second, and closely related to the first method, some of the fixtures may flood and overflow, owing to the passage of water from the stack through the fixture drain and trap back into the fixture. A failure of this kind implies a heavily overloaded stack or building drain, and again this would not be expected to occur on a single-story stack-vented system. The third method by which a plumbing system may fail is through the failure of the fixture traps to prevent the passage of sewer gas in objectionable amounts from the drainage system into the dwelling.

A fixture trap may fail in this manner by two methods. First, if the pressure reduction in the stack is sufficiently great, the water seal in the trap may be lowered excessively, so that adequate protection against the passage of sewer gas into the dwelling no longer exists. Or, secondly, the positive pneumatic pressures created in the drainage system by the discharge of other fixtures may be sufficiently high and of sufficient duration, even though the seal of the trap in question has not been reduced, to force sewer gas through the fixture trap in objectionable amounts, or the flow of sewer gas through the fixture traps may be sufficiently violent to throw a portion of the trap contents out of the fixture.

It became readily apparent as the tests progressed that a single-story stack-vented system could fail only through failure of the fixture traps to perform their function properly, and the tests were therefore designed to investigate those conditions which might cause maximum pressure reductions and maximum positive pressures in the stack at the points where the fixture drains connected to the stack.

The test results in which the water seals in the fixture traps were reduced by pressure reductions in the stack will be presented first.

In preliminary tests it was observed that the only fixtures subject to trap-seal losses were the tub and the water closet. The lavatory is subject to trap-seal losses only through self-siphonage effects, and, if the drain is short enough and if its slope is low enough, self-siphonage of the trap can be made negligible. While the combination fixture was connected in these tests to the stack below the lavatory and hence was stack-vented, the rate and volume of flow from the lavatory were so small that no trap-seal losses of the combination fixture trap were observed. Hence it may be concluded that the combination fixture, like the lavatory, will be subjected to trap-seal losses only if its drain is so long or is laid on so steep a slope that self-siphonage effects will become apparent. Under these circumstances, although the whole group of bathroom fixtures and the combination fixture is stack-vented, only the water closet and bathtub are subject to trap-seal losses attributable to that fact.

In many installations the stack-vented water closet and bathtub are subjected to the discharge of only the lavatory. In none of the tests, when the lavatory was discharged alone or in any combination with the stack-vented bathtub or water closet, was any trap-seal loss observed. Hence it may be stated without any further presentation of data that the stack-venting of a bathtub or a water closet on the top floor of a building is entirely permissible, provided only a lavatory discharges into the stack above the stack-vented bathtub or water closet in question. The problem as to the permissibility of stack venting the top-floor fixtures in general then becomes one of determining whether the connection of a sink or combination fixture to the stack above the stack-vented water closet and tub will result in failure of the water closet or tub traps to perform their function satisfactorily.

Preliminary tests indicated that the discharge of the water closet or tub, in addition to the sink, tray, or lavatory had no appreciable effect on either the tub or water-closet trap seals. These data are given in table 1.

TABLE 1. *Effect on the trap-seal loss of a stack-vented fixture of discharging another fixture the drain from which connects to the stack at the same level*

[The combination fixture was installed with a conventional metal trap and drain. The stack and piping were made of plastic material. Each value represents the maximum or average reading of five tests made under identical conditions]

Fixtures discharged	Trap-seal reduction			
	Tub		Water closet	
	Maximum	Average	Maximum	Average
	in.	*in.*	*in.*	*in.*
Sink and lavatory	0.75	0.62	1.00	0.90
Sink, lavatory, and bathtub	0.0	0.0	1.12	1.07
Sink, lavatory, and water closet	.88	.65	0.0	0.0
Sink, lavatory, and tray	1.00	.97	1.50	1.42

It is apparent from table 1 that the addition of the water closet or bathtub to the test loading consisting of the simultaneous discharge of the sink and lavatory causes only minor and inconsequential increases in the trap-seal losses of the stack-vented bathtub and water closet. It is also clear from table 1 that the addition of the tray to the test loading of sink and lavatory causes a substantially greater increase in trap-seal loss than does the addition of either the water closet or tub. As will be shown presently, the probability of the simultaneous discharge of more than two, or at most, three, of the fixtures under consideration is so remote as to be negligible. Hence it appears obvious that the test loading or loadings adopted for determining the adequacy of stack venting should consist of some combination of discharge of the fixtures connecting to the stack above the stack-vented bathtub and water closet. For this reason, all subsequent tests were made with various combinations of the discharge from the sink, tray, and lavatory.

It was found in the tests on the single-story stack-vented system that, as was to have been expected, trap-seal losses of the tub and water closet varied greatly with the rate of discharge from the fixtures above the tub and water closet, and the discharges from these fixtures, in turn, varied greatly with the dimensions of the trap and drain attached to these fixtures and with other dimensions of the system. For this reason, the tests were repeated with different trap sizes and with other variations in the set-up.

In order that the physical phenomena involved in stack venting might be observed visually, many of the tests were made with the fixture drains, traps, and vent fittings, as well as the stack, made of plastic tubing. These tests, as well as those made with conventional metal fixture traps, drains, and vent fittings, will be reported.

Tables 2 and 3 give test results for the 1½-inch-diameter combination-fixture drain with a short-turn fitting connecting the fixture drain to the 3-inch-diameter stack. All of the data of tables 2 and 3 were obtained with conventional metal traps and drains on the combination fixtures with a metal fitting connecting the drain to the transparent plastic stack. Many other tests were made with the combination-fixture trap and drain made of the plastic tubing. In general, the trap-seal losses of the water closet and tub were greater when

TABLE 2. *Trap-seal losses of a stack-vented water closet*

[Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. Each of the trap-seal losses given below represents the maximum or average of 10 tests made under identical conditions. A sanitary tee was used in all cases to connect the drain from the combination fixture to the stack. The piping, other than that used with the combination fixture and building sewer, was of plastic material.]

Fixtures discharged		Trap used with combination fixture									
		1½-in. wrought iron		1½-in. cast brass		1½-in. streamlined copper		1½-in. brass tubing			
	Height of combination fixture drain above water closet drain ... *in.*	18	18	18	18	18	18	18	18	20.5	20.5
		1st ser.	2d ser.	1st ser.	2d ser.	1st ser.	2d ser.	1st ser.	2d ser.	1st ser.	2d ser.
Sink	Flow rate ... *gpm*	34.6	35.2	30.3	30.8	33.8	35.8	37.5	37.2	35.4	35.5
	Trap-seal loss, max ... *in.*	0.25	0.25	0.38	0.12	0.50	0.50	0.38	0.38	0.25	0.38
	Trap-seal loss, avg ... *in.*	.25	.25	.33	.12	.40	.50	.38	.33	.25	.30
Sink and tray [1]	Flow rate ... *gpm*	35.3	35.2	30.4	31.4	36.5	37.0	38.7	38.9	36.7	37.3
	Trap-seal loss, max ... *in.*	0.38	0.38	0.38	0.38	0.50	0.62	0.62	0.75	0.50	0.50
	Trap-seal loss, avg ... *in.*	.38	.38	.38	.27	.48	.58	.57	.67	.50	.50
Sink and lavatory [1]	Flow rate ... *gpm*	46.0	45.9	41.7	41.8	46.8	46.0	49.5	48.4	46.7	47.8
	Trap-seal loss, max ... *in.*	1.00	0.88	0.50	0.50	*1.12*	*1.12*	0.88	1.00	0.88	0.88
	Trap-seal loss, avg ... *in.*	0.85	.76	.47	.50	*1.05*	1.00	.86	.96	.77	.88
Sink, tray, and lavatory	Flow rate ... *gpm*	46.8	47.1	41.4	41.4	48.9	47.5	49.4	50.2	48.6	48.0
	Trap-seal loss, max ... *in.*	*1.12*	1.00	0.75	0.62	*1.50*	*1.50*	*1.25*	*1.50*	*1.25*	1.00
	Trap-seal loss, avg ... *in.*	0.90	1.00	.70	.52	*1.32*	*1.30*	*1.23*	*1.45*	*1.10*	1.00

[1] Adopted test loadings.

a smooth plastic trap and drain were used with the combination fixture than when these items were of metal. This result could have been expected, since the rate of discharge of the combination fixture is somewhat greater with the plastic trap and drain than with the conventional metal ones.

It will be noted that tables 2 and 3 do not list trap-seal losses of the water closet or the bathtub when the tray is discharged alone or in combination with the lavatory. Preliminary tests showed that trap-seal losses for these loadings were negligible compared with those which included the discharge of the sink.

For the conditions under which the data in tables 2 and 3 were obtained, these tables may be used to determine the permissibility of stack-venting a bathtub and water closet when a lavatory and combination fixture connect to the stack above the water closet and bathtub in question.

TABLE 3. *Trap-seal losses of a stack-vented bathtub with a drain 38 in. long laid on a slope of ½ in./ft*

Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. The data represent the maximum and average of 10 tests under identical conditions. A sanitary tee was used in all cases to connect the combination-fixture drain to the stack. When the plastic traps were tested, the combination-fixture drain and the sanitary tee connecting it to the stack were also of plastic material. When the metal traps were used, the drain and the sanitary tee were also of metal]

Fixtures discharged		Trap used with combination fixture						
		1½-in. wrought iron	1½-in. cast brass	1½-in. stream-lined copper	1½-in. brass tubing			
	Height of combination-fixture drain above water-closet drain____in__	18	18	18	18	18	20.5	20.5
Sink	Flow rate____gpm__	35.2	30.8	35.8	37.2	----------	35.4	----------
	Trap-seal loss max____in__	0.25	0.38	0.25	0.75	----------	0.38	----------
	Trap-seal loss avg____in__	.23	.38	.12	.42	----------	.30	----------
Sink and tray [1]	Flow rate____gpm__	35.2	30.4	37.0	38.9	----------	36.7	----------
	Trap-seal loss max____in__	.50	0.50	0.75	*1.25*	----------	0.50	----------
	Trap-seal loss avg____in__	.42	.43	.56	0.99	----------	.50	----------
Sink and lavatory [1]	Flow rate____gpm__	45.9	41.7	46.0	48.7	48.4	45.5	46.4
	Trap-seal loss max____in__	0.50	0.50	0.62	0.88	0.88	0.62	0.50
	Trap-seal loss avg____in__	.42	.45	.50	.75	.43	.60	.50
Sink, tray, and lavatory	Flow rate____gpm__	47.1	41.4	47.5	49.6	50.2	48.2	48.6
	Trap-seal loss max____in__	0.62	0.62	1.00	1.00	*2.00*	*1.12*	0.75
	Trap-seal loss avg____in__	.62	.57	0.72	0.98	*1.23*	0.77	.75

[1] Adopted test loading.

VII. Interpretation of Test Results

In determining the adequacy of a drainage system with a particular type of venting, it is necessary first to determine by experiment the trap-seal losses that occur in the system under various loading conditions. This has been done for the 3-inch stack in tables 2 and 3. Secondly, it is necessary to establish a criterion of satisfactory trap performance, that is, to establish a dividing line between trap-seal losses that may be considered satisfactory and those that may be considered sufficiently large to impair the ability of the trap to prevent the entrance into the dwelling of sewer gas in objectionable amounts. And third it is necessary to establish a criterion of what constitutes a reasonable test loading. That is, it is necessary to select a portion of those fixtures on the system, the use of which can be assumed to occur simultaneously with reasonable frequency, to serve as a guide in determining whether a trap-seal loss caused by the discharge of a particular group of fixtures is a sound basis for rejecting or accepting stack venting of plumbing fixtures as an adequate method of venting.

To summarize, tables 2 and 3 present trap-seal losses of stack-vented fixtures under certain conditions. In order to apply these data to the problem of determining if stack-venting of plumbing fixtures is admissible, it is necessary (1) to determine what trap-seal losses are permissible and (2) what combination of simultaneous fixture discharges is likely to occur. The latter problem will be considered first.

1. Probable Loads From a Single Group of Bathroom Fixtures and a Combination Fixture

This problem, insofar as the question of the adequacy of stack venting of plumbing fixtures is concerned, is simplified somewhat by the data in table 1. These data indicate that the discharge of either the tub or the water closet will have little or no effect on trap-seal losses. Consequently, attention may be confined to the lavatory and the sink and tray compartments of the combination fixture.

There are no data available on the frequency of use of the lavatory, sink, and laundry tray in single-family dwellings, but a consideration of the usual habits of family living would indicate that the simultaneous drainage of any two of the fixtures would occur only infrequently and that the use of all three at the same time would occur very rarely. For example, assume that the sink compartment of the combination fixture is filled and discharged at random once every 5 minutes, the tray compartment once every 10 minutes, and the lavatory once every 3 minutes. The duration of flow from these fixtures will be approximately 15 seconds for the sink, 40 seconds for the tray, and 9 seconds for the lavatory.

At any arbitrarily chosen instant of observation the probability, P, that all three of these fixtures will be found discharging is

$$P=\frac{15}{300}\times\frac{40}{600}\times\frac{9}{180}=0.000167,$$

or approximately 1 in 6,000.

Obviously, the simultaneous discharge of the sink and tray compartments of the combination fixture and the lavatory will occur very infrequently. For this reason the simultaneous discharge of these fixtures cannot be considered a reasonable test load on which to base the acceptance or rejection of any venting or drainage system. In this connection it may be observed that Hunter [6] has recommended that plumbing systems be designed to carry only those loads whose probability of occurrence is greater than 0.01, and loading tables based on this probability of occurrence have been used for a number of years by some of the Federal departments, apparently with satisfactory results.

The values for the frequency of discharge of the sink, tray, and lavatory used above correspond in general to the frequency of use of identical or similar fixtures in public washrooms given by Hunter [6, 7] and do not represent an estimate of use of these fixtures in private dwellings, such as we are here considering. The frequencies of use of these fixtures, used in the computation of the probability of their coincident discharge, are obviously higher than would be found in the usual private dwelling and have been used merely to demonstrate that, under the most severe loading conditions, it is not reasonable or logical to assume that the proper test loading should consist of the combined simultaneous discharge of the sink and tray compartments of the combination fixture and the lavatory.

The probability, P, of the simultaneous discharge of either the sink and tray or the sink and lavatory, with the third fixture not discharging is

$$P=\frac{15}{300}\times\frac{9}{180}\times\frac{560}{600}+\frac{15}{300}\times\frac{40}{600}\times\frac{171}{180}=0.0055,$$

or approximately 1 in 180. The probability that the sink and tray or the sink and lavatory will be in use at any instant of observation is thus approximately 30 times as great as for the simultaneous discharge of all three fixtures and is sufficiently large to make the selection of these combinations of fixture discharge as suitable test loads both reasonable, and not overly conservative, in determining the adequacy of stack venting.

2. Permissible Trap-Seal Losses

As has been stated previously, the function of a fixture trap is to prevent sewer gas in objectionable amounts from entering the dwelling. A trap-seal loss which does not prevent a trap from performing this function under the pressure conditions prevailing in the drain or stack at the point where it is vented cannot be considered objectionable. If a pressure reduction of sufficient magnitude exists in a stack at a point where the drain of a stack-vented fixture connects to the stack, air will be drawn from the dwelling through the trap and into the drainage system. Obviously this phenomenon can in no way endanger the occupants of the building nor impair in any manner the operation of the drainage system. It is apparent that the only manner in which a reduction in seal of a stack-vented fixture trap might be objectionable would be through the reduction in its ability to prevent air from being forced under positive pressure from the stack through the trap and into the dwelling. In a single-story system or on the top floor of any system it is clear from Dawson's and Kalinske's data [1] that positive pressures, immediately below the point of water entrance. do not occur under normal conditions. It might be concluded, therefore, insofar as stack-vented fixtures on the top floor of the usual system are concerned, that any trap-seal loss which does not completely and permanently destroy the seal would be satisfactory.

However, as will be seen presently, it is sufficient for the purpose of this investigation to assume the more conservative requirement first stated in "Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings" [2] that, for traps having a 2-inch depth of seal, the seal loss shall not exceed 1 inch. In applying this criterion of satisfactory trap performance, we shall use the maximum trap-seal loss observed in 10 consecutive tests made under identical conditions.

3. Conclusions

Knowing the permissible trap-seal loss and the assumed maximum loading of the system derived above, we can use the data in tables 2 and 3 to determine directly the adequacy of single-story stack-vented systems in which the combination-fixture drain is 1½ inches in diameter and the drain is connected to the stack by a short-turn fitting.

Reference to table 2 will show that, for the loadings of sink and tray or sink and lavatory, a trap-seal loss of 1 inch, for the stack-vented water closet was exceeded only 3 times by the maximum seal losses listed, and then by only ⅛ inch. In view of the fact that the basket strainer was completely pulled out of the sink on these tests, and the fixtures were filled to a greater depth than will be found convenient or will occur frenquently in practice, it is concluded that the three minor deviations in table 2 for the loadings of sink and tray, and sink and lavatory, from the adopted criterion of satisfactory trap-seal reduction, are negligible and inconsequential.

It is apparent, for combination-fixture drains of $1\frac{1}{2}$-inch diameter connecting to a 3-inch-diameter stack through a sanitary fitting, that the stack venting of a water closet in a single story installation on the top floor of any system is a satisfactory method of venting.

From table 3, for bathtubs with drains 38 inches long on a $\frac{1}{2}$-inch-per-foot slope, it will be noted that for the adopted test loading of sink and lavatory or sink and tray, there was only one instance in which the adopted criterion of satisfactory trap-seal loss was exceeded. Inasmuch as this criterion was exceeded only once, and then by only $\frac{1}{4}$ inch, and in view of the safety factors introduced by the methods of the tests and by the adopted criterion of satisfactory trap-seal loss, it is concluded that this single deviation from the adopted standard of satisfactory trap-seal loss is of minor importance and can be neglected, and hence the stack-venting of bathtubs with drains 38 inches long on $\frac{1}{2}$-inch-per-foot slope may be considered a satisfactory method of venting.

In practice, of course, other lengths and slopes of bathtub drains are used. In like manner, the above conclusions are based on tests with $1\frac{1}{2}$-inch-diameter combination-fixture drains, and in practice larger diameters are sometimes used. The effect of change in these dimensions and the effect of other variables on the above conclusions will be investigated.

VIII. Factors Affecting the Performance of Stack-Vented Fixtures

1. Rate of Fixture Discharge

As would be expected, it was found that the trap-seal losses of stack-vented fixtures increase with increase in the rate of flow from the fixtures connected to the stack above the stack-vented fixture in question. The data of tables 2 and 3, together with results of tests with transparent plastic traps and drains, have been plotted in figures 6 and 7.

It will be observed from these figures that combined rates of flow of 40 gallons per minute from the sink and tray or 48 gallons per minute from the sink and lavatory will cause an average trap-seal loss of approximately 1 inch in either the stack-vented water closet or bathtub.

Reference to tables 2 and 3 will show that with fixtures in common use, these rates of flow are closely approached or slightly exceeded when the basket-type strainer is completely withdrawn from the sink compartment of the combination fixture. It is obvious that any future change in fixture design that increases appreciably the rates of flow from the lavatory or the sink and tray compartments of the combination fixture may cause excessive trap-seal losses of stack-vented fixtures connected to a 3-inch-diameter stack.

2. Diameter of Stack

All of the tests in this investigation were made on a 3-inch-diameter stack. However, 4-inch-diameter stacks are sometimes required by plumbing codes, even for a single-story system; and on multistory systems, where it may be desirable

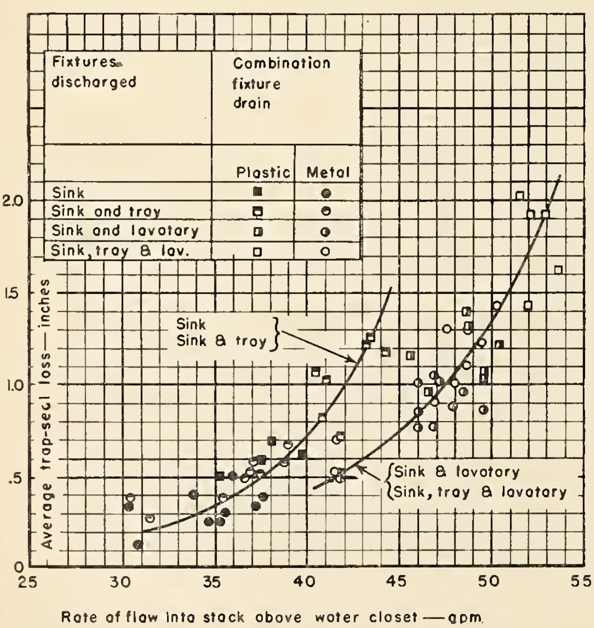

FIGURE 6. *Trap-seal losses of a stack vented water closet.*

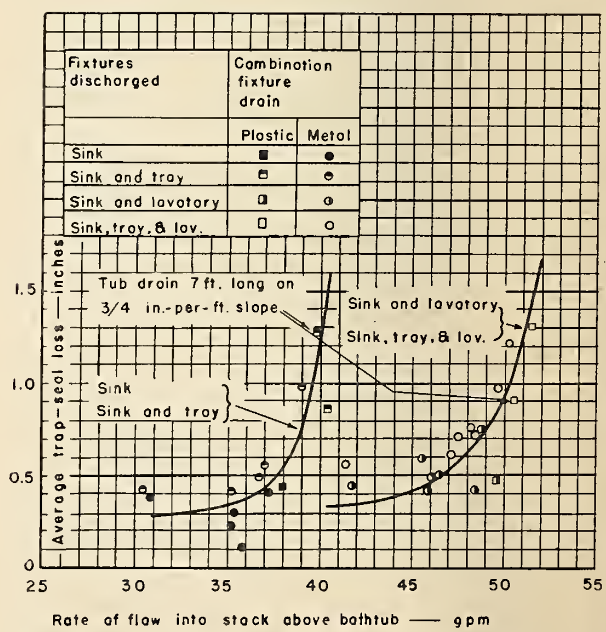

FIGURE 7. *Trap-seal losses of a stack-vented bathtub.*

to stack-vent the top-floor fixtures, the stack may be even larger. The question therefore arises as to whether conclusions based on tests made with 3-inch-diameter stacks would also be valid for stacks of larger diameter.

In this connection Dawson and Kalinske [2] have demonstrated that, for a given volume rate of flow into a stack, the pressure reduction below the point of water entrance will decrease as the diameter of the stack increases. Since the trap-seal loss observed in a stack-vented fixture trap, when fixtures connected to the stack above it are discharged, is caused by the pressure reduction created in the stack by the discharge of the upper fixtures, it follows from Dawson and Kalinske's data that the seal losses of stack-vented fixtures will decrease, for a given fixture discharge above the fixture in question, as the diameter of the stack is increased. Therefore, it may be stated that the conclusions expressed previously as to the adequacy of stack venting of fixtures connected to a 3-inch-diameter stack, will be at least equally valid for stacks of greater diameter.

3. Vertical Distance Between Bathtub or Water-Closet Drain and Combination-Fixture Drain

Fixtures are connected to a stack at various heights above floor level, depending on custom and on convenience. For this reason tests were made with the combination-fixture drain connected to the stack at various distances above the water-closet and tub drains. This dimension was varied by using different lengths of tail pieces on the combination fixture. The height of the rim of the fixture above floor level was held constant at 39 inches.

Variation in the vertical distance between the water-closet or tub drain and the combination fixture drain can affect trap-seal losses of the stack-vented tub or water closet in two ways. First, an increase in this dimension will cause a decrease in the rate of flow from the higher fixtures, since it involves a decrease in the head tending to produce flow from these fixtures; and, second, from Dawson and Kalinske's data [1], it is apparent that the pressure reduction in the stack varies with the distance below the point of water entrance, and it would therefore be expected that trap-seal losses of stack-vented fixtures would also vary with this dimension.

Test results for the combination fixture drain 18 and 20.5 inches above the water-closet and bathtub drains have been given in tables 2 and 3. In table 4 data for the combination fixture drain 15.5 inches above the water closet and tub drains are compared with similar data obtained with this dimension equal to 18.0 inches.

It will be observed from tables 2 and 3 that the effect of decreasing the dimension in question from 20.5 to 18 inches is, consistently, to increase both the rate of discharge from the combination fixture and the seal losses in the traps of the water closet and bathtub. From table 4 it is apparent that the further decrease of this dimension from 18 to 15.5 inches, in the case of bathtubs, will cause a substantial decrease in seal losses, and in the case of water closets only a minor and inconsequential increase. Since the seal losses of stack-vented bathtubs are a maximum when the combination-fixture drain is approximately 18 inches above the tub drain, it is clear that the conclusions based on table 3 will hold for all bathtub installations in which the stack-vented bathtub is subjected to the flow from a lavatory and combination fixture located on the same floor level.

In like manner, since the tests have shown, (1) that the trap-seal losses of a stack-vented water closet will be decreased by increasing the dimension in question above 18 inches, and (2) that trap-

TABLE 4. *Trap-seal losses of stack-vented fixtures at various distances below point of water entrance to stack*

[Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests]

Fixtures discharged		Trap-seal losses of Water closet		Trap-seal losses of Bathtub	
		Distance of water-closet and bathtub drain below combination-fixture drain (in.)			
		15.5	18.0	15.5	18.0
Sink	Flow rate, gpm	39.6	37.4	39.8	37.2
	Trap-seal loss, max, in	0.38	0.38	0.12	0.75
	Trap-seal loss, avg, in	.37	.36	.07	.42
Sink and tray	Flow rate, gpm	41.6	38.8	42.1	38.9
	Trap-seal loss, max, in	0.81	0.68	0.75	*1.25*
	Trap-seal loss, avg, in	.68	.62	.58	0.99
Sink and lavatory	Flow rate, gpm	50.5	49.0	49.4	48.7
	Trap-seal loss, max, in	*1.06*	0.94	0.62	0.88
	Trap-seal loss, avg, in	*1.01*	.91	.45	.75
Sink, tray, and lavatory	Flow rate, gpm	52.4	49.8	52.1	49.6
	Trap-seal loss, max, in	*1.50*	*1.38*	1.00	1.00
	Trap-seal loss, avg, in	*1.38*	*1.33*	0.62	0.98

seal losses are substantially constant for a change in this dimension from 18 to 15.5 inches, and since Dawson and Kalinske's work [1] has shown that decrease in stack pressure becomes less as this distance is decreased below approximately 18 inches, it may also be stated that the conclusions based on the data of table 2 will hold for all water-closet installations in which the stack-vented water closet is subjected to the flow from a lavatory and combination fixture located on the same floor level.

4. Diameter of Combination Fixture Drain

The data in tables 2 and 3 were obtained with a 1½-inch-diameter fixture drain. However, in practice, combination-fixture or sink drains 2 inches in diameter are sometimes installed. For this reason, the effect of change in diameter of the combination-fixture drain on trap-seal losses of the stack-vented water closet and bathtub was investigated, and the test results are given in tables 5, 6, and 7.

It will be observed that with the fixtures and traps tested, an increase in diameter of the combination-fixture drain caused, insofar as the 1½- and 2-inch-diameter drains are concerned, a decrease in trap-seal losses. It is apparent, therefore, that the data of tables 2 and 3 for 1½-inch-diameter combination-fixture drain, and the conclusions based on them will apply with at least equal safety to an installation with a 2-inch-diameter combination-fixture drain.

It is interesting to note in tables 5, 6, and 7 that, while an increase in the diameter of the combination-fixture drain from 1½ to 2 inches caused decreased trap-seal losses, it also caused an increased rate of discharge from the fixture, and we have the unexpected result that an increased rate of flow into the stack is accompanied by a decrease in trap-seal losses. In like manner, the decrease in diameter of the combination-fixture drain from 1½ to 1¼ inches resulted in a decreased rate of discharge, for the test loads adopted, accompanied by an increase in the trap-seal losses of the bathtub and substantially the same seal losses for the water closet.

Obviously, the pressure reduction in a stack immediately below the point of water entrance is not only a function of the volume rate of inflow, but it is also a function of some other variable, the diameter of the drain admitting water to the stack, or, what amounts to the same thing, the velocity of the inflowing water. In this connection it appears reasonable to assume that the trap-seal losses, h, in stack-vented systems which are otherwise geometrically similar will depend on Q, the volume rate of flow past the level at which the drain of the stack-vented fixture in question connects to the stack, d_1, the diameter of the stack, d_2, the diameter of the horizontal or fixture branch through which water enters the stack, z, the vertical distance between the point at which the drain from the stack-vented fixture enters the stack and the point of water entrance, γ_w, the specific weight of the water, γ_a, the specific weight of the air, and g, the acceleration of gravity.

We can express this mathematically by writing

$$h = \text{function}\ (Q, d_1, d_2, z, \gamma_w, \gamma_a, g). \qquad (1)$$

Using the customary methods of dimensional analysis, we may write eq 1 in the form

$$\frac{h}{d_1} = f\left(\frac{d_2}{d_1}, \frac{z}{d_1}, \frac{Q}{d_1^2\sqrt{gd_1}}, \frac{\gamma_w}{\gamma_a}\right). \qquad (2)$$

TABLE 5. *Effect of change in diameter of combination-fixture drain on trap-seal losses of stack-vented water closets*

[Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. The combination-fixture drain, which was 16 in. long, was connected to the 3-in. stack through a sanitary tee fitting at a point 18 in. above the water-closet drain. The data given below are based on 10 tests made under identical conditions.]

Fixtures discharged		1⅜-in.-diameter plastic trap on combination fixture				2-in.-diameter metal trap on combination-fixture and 2-in.-diameter metal drain on combination fixture	
		1¼-in.-diameter plastic drain on combination fixture		1½-in.-diameter plastic drain on combination fixture			
		1st ser.	2d ser.	1st ser.	2d ser.	1st ser.	2d ser.
Sink	Flow rate, gpm	34.9	34.8	38.0	39.8	41.2	40.3
	Trap-seal loss, max, in.	0.75	0.75	0.75	0.62	0.62	0.50
	Trap-seal loss, avg, in.	.64	.67	.70	.62	.57	.50
Sink and tray [1]	Flow rate, gpm	35.7	36.0	40.4	41.0	44.6	45.4
	Trap-seal loss, max, in.	*1.12*	*1.12*	*1.12*	*1.12*	1.0	1.0
	Trap-seal loss, avg, in.	*1.02*	*1.05*	*1.07*	*1.02*	.90	1.0
Sink and lavatory [1]	Flow rate, gpm	45.5	45.6	49.6	49.5	51.1	50.4
	Trap-seal loss, max, in.	*1.38*	*1.38*	*1.12*	*1.38*	.88	1.0
	Trap-seal loss, avg, in.	*1.19*	*1.19*	*1.04*	*1.07*	.88	.97
Sink, tray, and lavatory	Flow rate, gpm	47.0	47.0	51.5	52.1	56.7	56.8
	Trap-seal loss, max, in.	*1.50*	*1.50*	*2.12*	*2.0*	*1.50*	*1.38*
	Trap-seal loss, avg, in.	*1.50*	*1.50*	*2.02*	*1.92*	*1.47*	*1.38*

[1] Adopted test loadings.

As far as the method of dimensional analysis, unassisted by any physical considerations, is concerned, other forms of eq 2, particularly as regards the variables h/d_1 and $Q/d_1^2\sqrt{gd_1}$, can be obtained. The form given above will be found convenient in one of the later applications in the paper, while in another application it will be found preferable to replace $Q/d_1^2\sqrt{gd_1}$ by $Q/d_1^2\sqrt{gd_2}$.

For all practical purposes, γ_w and γ_a will be constant in the tests described here, and hence the term γ_w/γ_a can be treated as a constant. For a given value of z/d_1, then, eq 2 becomes

$$\frac{h}{d_1}=f\left(\frac{d_2}{d_1}, \frac{Q}{d_1^2\sqrt{gd_1}}\right). \tag{3}$$

This grouping of the variables has been used in figure 8 to plot the data given in tables 2 and 5 for water closets for the simultaneous discharge of the sink and tray compartments of the combination fixture or the sink compartment alone. Similar data obtained with smooth plastic fixture-traps and drains have also been plotted in figure 8.

In figure 9 the data for bathtubs from tables 3 and 7 have been plotted, together with test results obtained with smooth plastic fixture traps and drains.

From these figures it is evident that, for a given size of stack and a given volume rate of inflow, an increase in d_2, which, of course, corresponds to a decrease in the velocity of inflow, will cause a decrease in trap-seal losses of stack-vented fixtures.

Although the data plotted in figures 8 and 9 are for stacks 3 inches in diameter, it is to be expected from eq 3 that the curves would hold for stacks of any diameter.

Table 6. *Effect of changes in diameter of combination-fixture drain on trap-seal losses of stack-vented bathtub*

[Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. The combination fixture drain, which was 16 in. long, was connected to the 3-in. stack through a sanitary tee fitting at a point 18 in. above the water-closet drain. The data given below are based on 10 tests made under identical conditions.]

Bathtub drain 38 in. long on ¼-in.-per-foot slope

Fixtures discharged		1⅜-in.-diameter plastic trap on combination fixture: 1¼-in.-diameter plastic drain on combination fixture	1⅜-in.-diameter plastic trap on combination fixture: 1½-in.-diameter plastic drain on combination fixture	2-in.-diameter metal trap on combination-fixture and 2-in.-diameter metal drain on combination fixture
Sink	Flow rate, gpm	34.8	39.8	40.3
	Trap-seal loss, max, in	0.75	0.38	0.0
	Trap-seal loss, avg, in	.67	.28	.0
Sink and tray[1]	Flow rate, gpm	36.0	41.0	45.4
	Trap-seal loss, max, in	*2.00*	0.0	0.0
	Trap-seal loss, avg, in	*1.90*	.0	.0
Sink and lavatory.[1]	Flow rate, gpm	45.6	49.5	50.4
	Trap-seal loss, max, in	*1.62*	0.38	0.25
	Trap-seal loss, avg, in	0.92	.28	.17
Sink, tray, and lavatory.	Flow rate, gpm	47.0	52.1	56.8
	Trap-seal loss, max, in	*2.25*	0.0	0.0
	Trap-seal loss, avg, in	*2.17*	.0	.0

[1] Adopted test loadings.

Table 7. *Effect of changes in diameter of combination-fixture drain on trap-seal losses of stack-vented bathtub*

[Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. The combination fixture drain, which was 16 in. long, was connected to the 3-in. stack through a sanitary tee fitting at a point 18 in. above the bathtub drain. The data given below are based on 10 tests made under identical conditions.]

Bathtub drain 38 in. long on ½-in.-per-foot slope

Fixtures discharged		1⅜-in.-diameter plastic trap on combination fixture: 1¼-in.-diameter plastic drain on combination fixture	1⅜-in.-diameter plastic trap on combination fixture: 1½-in.-diameter plastic drain on combination fixture	2-in.-diameter metal trap on combination-fixture and 2-in.-diameter metal drain on combination fixture
Sink	Flow rate, gpm	34.9	38.0	41.2
	Trap-seal loss, max, in	0.75	0.62	0.25
	Trap-seal loss, avg, in	.60	.45	.17
Sink and tray.[1]	Flow rate, gpm	35.7	40.4	44.6
	Trap-seal loss, max, in	*2.12*	1.00	0.88
	Trap-seal loss, avg, in	*1.97*	0.87	.45
Sink and lavatory.[1]	Flow rate, gpm	45.5	49.6	51.1
	Trap-seal loss, max, in	1.00	0.62	0.50
	Trap-seal loss, avg, in	0.90	.49	.28
Sink, tray, and lavatory.	Flow rate, gpm	47.0	51.5	56.7
	Trap-seal loss, max, in	*2.12*	*1.62*	1.00
	Trap-seal loss, avg, in	*1.92*	*1.32*	0.60

[1] Adopted test loadings.

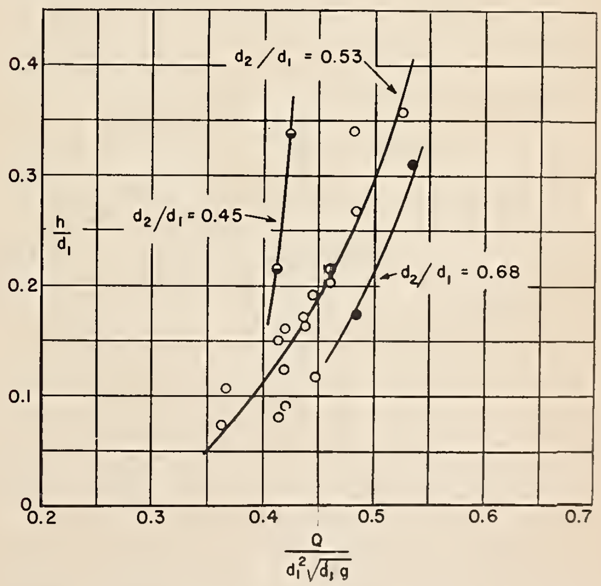

Figure 8. *Relative trap-seal losses for a stack-vented water closet.*

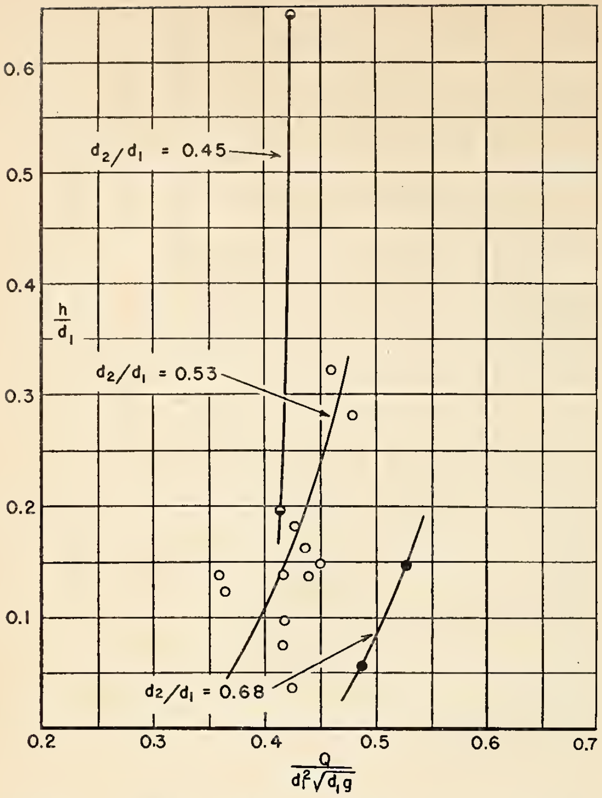

FIGURE 9. *Relative trap-seal losses for a stack-vented bathtub.*

5. Length and Slope of Bathtub or Water-Closet Drains

In a group of stack-vented fixtures, as has been stated prevously, the flow from the lavatory and combination fixture causes a negative pressure in the stack which produces seal losses in the stack-vented bathtub and water-closet traps. However, this is only one facet of the phenomenon that occurs when a stack-vented bathtub loses its seal. In the tests described here, the bathtub drain entered the stack through a single 3-inch sanitary tee with a 1½-inch side inlet. That is, the water-closet and tub drains entered the stack at the same elevation through a standard side-inlet fitting. This fitting, shown in figure 5, was made of transparent plastic material and was identical in internal dimensions with the usual threaded-type 3-inch sanitary tee with a 1½-inch side inlet. The radius of curvature of this type of fitting where the 1½-inch side inlet joins the 3-inch stack is small, being approximately ¼ inch. With this type of fitting, a small portion of the water flowing down the stack enters the 1½-inch side inlet and forms a shallow pool in the tub drain, and, if the tub drain is short and on a sufficiently low slope, this pool will extend to the trap weir (see fig. 4) in which case the resulting flow of water from the stack though the tub drain and into the trap will reduce any trap-seal loss that may have been caused by a negative pressure in the stack. As long as the water surface of this pool extending from the stack back through the tub drain is higher than the level of the trap weir, there will be at least partial refill of the trap after the pressure in the stack has returned to atmospheric pressure. If the drain is sufficiently long and on a sufficiently high slope, so that the surface of the pool is lower than the level of the trap weir, no refill will take place, and maximum trap-seal losses will result.

The details of this phase of the problem were not investigated systematically, but enough data were obtained to verify the general description of the phenomenon given above and to indicate quantitatively the effect of variation in length and slope of the tub drain on trap-seal losses.

In table 8 are given seal losses for tub drains 38 inches long on a ¼-inch-per-foot slope. Comparison of these data with those given in table 3 for tub drains of the same length but on a ½-inch-per-foot slope indicates that, for the two slopes tested, the effect in general of reducing the slope for this length of drain is consistently to reduce tub trap-seal losses.

In table 9 are given trap-seal losses under certain loadings for bathtub drains 7 feet long on a slope of ¾ inch per foot. These data have been plotted in figure 7, and it will be observed that the results agree well with those obtained with the tub drain 38 inches long on a ½-inch-per-foot slope. In view of this fact, and in view of the fact that it was observed in the tests on the tub drain 38 inches long on a ½-inch-per-foot slope that refill of the tub trap did not occur, it is concluded that the trap-seal reductions observed on tests with a bathtub drain 38 inches or more in length on a ½-inch-per-foot slope or greater will be as great or greater than will occur for a bathtub drain of any length or any slope. Hence, the conclusions previously given as to the adequacy of stack venting, which were based on the data of table 3 will be valid for bathtubs with drains of any length or slope.

In the case of stack-vented water closets there is no possibility of refill of the trap from the fixture drain owing to the conventional type of installation which places the weir of the water-closet trap several inches above the horizontal portion of the water-closet drain. For this reason it appears obvious that the trap-seal reductions of stack-vented water closets will be independent of slope and length of water-closet drain, provided these factors are not such as to cause self-siphonage.

6. Type of Fitting Connecting Combination Fixture to Stack

All the experimental data given previously in this paper have been for a sanitary tee fitting connecting the combination-fixture drain to the stack. However, a long-turn fitting is also often used for this purpose in practice, and in like manner double fittings connecting the combination-fixture and lavatory drains to the stack are also frequently

TABLE 8. *Trap-seal losses of a stack-vented bathtub with a drain 38 inches long on a slope of 1/4 in. per ft.*

[The data represent the maximum and average of 10 tests made under identical conditions. A sanitary tee was used in all cases to connect the combination-fixture drain to the stack. When the plastic traps were tested, the combination-fixture drain and the sanitary tee connecting the drain to the stack were also made of plastic material. When the metal traps were used, the drain and sanitary tee were also made of metal.]

Fixtures discharged		Trap used with combination fixture							
		1½-in. wrought iron	1½-in. cast brass	1½-in. stream-lined copper	1½-in. brass tubing				
	Height of combination-fixture drain above water-closet drain ... in.	18	18	18	15.5	18.0	18.0	20.5	20.5
Sink	Flow ... gpm	34.6	30.8	33.8	39.5	37.5		35.5	
	Trap-seal loss, max. in.	0.0	0.25	0.12	0.0	0.38		0.0	
	Trap-seal loss, avg. in.	.0	.10	.07	.0	.25		.0	
Sink and tray [1]	Flow rate ... gpm	35.3	31.4	36.5	41.1	38.7		37.3	
	Trap-seal loss, max. in.	0.0	0.38	0.0	0.0	.62		0.0	
	Trap-seal loss, avg. in.	.0	.27	.0	.0	.47		.0	
Sink and lavatory [1]	Flow rate ... gpm	46.0	41.8	46.8	51.6	48.1	49.5	44.9	47.8
	Trap-seal loss, max. in.	0.50	0.38	0.50	0.0	0.50	0.75	0.50	.0.0
	Trap-seal loss, avg. in.	.22	.33	.50	.0	.15	.60	.42	.0
Sink, tray, and lavatory	Flow rate ... gpm	46.8	41.4	48.9	52.7	49.9	49.4	47.9	48.0
	Trap-seal loss, max. in.	0.12	0.38	0.38	0.0	0.12	0.62	0.0	0.0
	Trap-seal loss, avg. in.	.02	.38	.08	.0	.02	.38	.0	.0

[1] Adopted test loadings.

used. For these reasons tests were made with these fittings. The results of these tests, for stack-vented water closets, are shown in table 10 with comparable test results with the single sanitary or short-turn fitting. It will be observed that the long-turn fitting gave the smallest trap-seal losses and that the single short-turn fitting gave the greatest.

7. Trap Dimensions

There are two methods by which a tub trap-seal loss, due to negative pressures in the stack or fixture drain, may occur. First, if the negative pressure, expressed in inches of water, in the tub drain created by the flow down the stack is less than the depth of trap seal; then, assuming that the tub drain is sufficiently long and on a sufficiently high slope to prevent refill of the trap from the drain, water will be drawn from the trap until equilibrium occurs, and, when the flow in the stack ceases, the seal reduction in the tub trap will be one-half the magnitude of the negative pressure head in the tub drain, and is independent of the depth of the trap seal and of any other dimension of the trap, such as its diameter. However, if the flow down the stack is large enough to cause a pressure reduction in the tub drain greater than the depth of the tub trap-seal, air will be bubbled from the atmosphere through the trap into the tub drain. This process pumps water out of the tub trap and into the drain and hence results in relatively large trap-seal losses.

Consequently, it is apparent, for a given pressure reduction in the tub drain, that if the depth

TABLE 9. *Tub trap-seal losses for stack-vented bathtub drains 7 feet long on a slope of 3/4 in. per ft.*

Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. The data represent the maximum and average of 10 tests under identical conditions. A sanitary tee was used to connect the combination-fixture drain to the stack. The combination-fixture trap was 1⅝ in. in internal diameter and was made of transparent plastic material. The remainder of the drainage system was also made of plastic material, with the exception of the building sewer, which was cast iron.]

Fixtures discharged		
Sink and tray	Flow rate ... gpm	39.9
	Trap-seal loss, max ... in.	*1.75*
	Trap-seal loss, avg ... in.	*1.28*
Sink, tray, and lavatory	Flow rate ... gpm	50.5
	Trap-seal loss, max ... in.	*1.75*
	Trap-seal loss, avg ... in.	0.92
Lavatory	Flow rate ... gpm	10.5
	Trap-seal loss, max ... in.	0.0
	Trap-seal loss, avg ... in.	.0
Lavatory and water closet	Flow rate ... gpm	
	Trap-seal loss, max ... in.	0.0
	Trap-seal loss, avg ... in.	.0

TABLE 10. *Effect of type of fitting connecting combination fixture to stack on trap-seal reductions of stack-vented water closet*

[Figures in italics represent those trap-seal losses in excess of the standard of satisfactory trap performance adopted for these tests. The data were obtained from tests on the complete plastic drainage system shown in figure 2. The vertical distance between the combination-fixture and water-closet drain was 15.5 in. for the single short- and long-turn fittings and 22 in. for the double short-turn fitting.]

Fixtures discharged		Single short-turn fitting	Single long-turn fitting	Double short-turn [1] fitting
Sink	Rate of flow ... gpm			28.3
	Trap-seal loss, max ... in.	0.88		0.25
	Trap-seal loss, avg ... in.	.75		.19
Sink and tray	Rate of flow ... gpm		42.6	30.0
	Trap-seal loss, max ... in.	*1.58*	0.38	0.75
	Trap-seal loss, avg ... in.	*1.25*	.24	.52
Sink and lavatory	Rate of flow ... gpm		50.5	39.4
	Trap-seal loss, max ... in.	*2.00*	0.62	0.88
	Trap-seal loss, avg ... in.	*1.57*	.54	.76
Sink, tray, and lavatory	Rate of flow ... gpm		53.8	41.1
	Trap-seal loss, max ... in.	*2.12*	0.88	1.00
	Trap-seal loss, avg ... in.	*1.97*	.66	0.95

[1] The lavatory was also connected to this fitting.

of the tub trap-seal is greater than the pressure reduction in the drain, a decrease in depth of trap seal will have no effect on tub trap-seal losses until a point is reached at which the depth of trap seal is equal to the pressure reduction in the drain. Any further reduction in depth of trap seal will cause a rapid increase in trap-seal losses. Hence the effect of increasing the depth of tub trap-seal from a value less than the pressure reduction in the drain to a value greater will be in general to decrease trap-seal losses substantially. And the effect of increasing the depth of tub trap-seal, when it is at all times greater than the negative pressure in the tub drain, will be nil.

In the tests reported here, the depth of tub trap-seal was 2 inches or more, and the adopted criterion of satisfactory performance was a trap-seal reduction of 1 inch. A trap-seal reduction of 1 inch corresponds to a negative pressure in the tub drain of 2 inches. Hence, the particular tests on which the conclusions as to the adequacy of stack venting have been based were made with loadings which produced negative pressures in the tub drain equal to or less than the depth of trap-seal. It is apparent, therefore, that the conclusions expressed in this report for traps with depths of seal of 2 inches would not be changed by increasing the depth of trap-seal.

The diameter of the bathtub traps used in these tests was 1⅝ inch, corresponding to some of the nominal 1½-inch-diameter cast traps. However, in practice, traps such as 1½-inch-nominal diameter brass-tubing traps, which may have an actual diameter of as little as 1⅜ inch, are sometimes used. The question arises as to what effect this decrease in tub-trap diameter might have on the trap-seal losses observed in these tests. From the discussion above on the effect of change in tub trap-seal depths on tub trap-seal losses it is evident that a change in tub-trap diameter could have no effect on tub-trap seal losses, as long as these losses were less than 1 inch, which, as has been stated before, has been adopted in this report as the criterion of satisfactory trap performance. For this reason it is apparent that the conclusions expressed regarding stack venting apply with equal force to tub-trap diameters of any value.

For seal losses greater than 1 inch in a trap with a depth of seal of 2 inches, air will be drawn through the trap, as noted previously, and, when this condition arises, the diameter of the tub trap undoubtedly has some effect on the amount of trap-seal reduction. This problem was not investigated, but it would be expected that a decrease in tub-trap diameter would cause greater trap-seal losses.

From the above discussion of the effect of tub trap-seal depth and tub-trap diameter on the trap-seal losses of stack-vented bathtubs it would be expected that the lower portion of the curves in figures 6 to 9, corresponding to trap-seal losses of 1 inch or less would be identical for all traps, while the upper portion of the curves, corresponding to trap-seal losses of more than 1 inch would vary according to the depth of trap seal and possibly the diameter of the trap.

While the above discussion has been confined to bathtub traps, it is evident that it would also apply to a stack-vented water closet or other fixture.

8. Submerged House Drain

The increased positive pressures in a plumbing drainage system caused by submerging the outlet end of the house sewer have been observed by Hunter [2], Babbsitt [3], and Dawson and Kalinske [4]. These increased positive pressures occur in stack-vented systems, as well as in systems with other types of venting.

When the two upper fixtures in the system shown in figure 1 are discharged, a negative pressure normally occurs in the stack at the point where the stack-vented bathtub and water closet connect to the stack, and trap-seal losses of these fixtures result. However, if the house or building sewer is sufficiently submerged by the water flowing in the street sewer, it is possible, under certain conditions, to obtain a momentary positive pressure in the stack at the point where the stack-vented water closet and bathtub connect to the stack. It is obvious that, if these positive pressures are sufficiently great, sewer gas or air will be forced out of the system through the water-closet and bathtub traps and into the dwelling.

There are three types of stack-vented installations to be considered in this connection. They are (1) a stack-vented group of bathroom and kitchen fixtures on the top floor of a multistory building in which vented fixtures connect to the stack at lower levels, (2) a single-story installation in which only a single bathroom group of fixtures is stack-vented, and (3) a single-story installation in which a kitchen sink or combination fixture, as well as a single bathroom group of fixtures, are stack-vented.

In a multistory system, the top floor of which is stack-vented, the positive pressures in the stack due to submergence of the building sewer will be confined to the lower portion of the stack, and will be relieved by the vents to the fixtures on the lower floors. It is apparent, therefore, that in multistory systems positive pressures due to submergence of the building or house sewer will not occur in the stack at the top floor and hence cannot cause stack-vented fixtures on this floor to operate improperly.

With regard to the second type of stack-vented installation, in which only a single group of bathroom fixtures is stack-vented on a single-story system, tests made on the system shown in figure 1 with the street sewer flowing full, and tests made on the laboratory arrangement shown in figure 10 demonstrated that the discharge of the lavatory, tub, and water closet, in coincidence or in any combination, will not cause positive pressures sufficiently large to break the seal of any trap. Hence, it is apparent that the performance of a stack-vented single group of bathroom fixtures on a single-story stack will not be adversely affected by submergence of the house sewer.

With regard to the third type of installation noted above where a stack-vented sink or combination fixture, as well as a stack-vented group of bathroom fixtures, are connected on one floor level to a single-story stack, without vents of any kind connecting to the stack at a lower level, tests made on the system of figure 1 with the street sewer flowing full so as to submerge the house sewer, and tests on the system of figure 10 with various amounts of submergence of the house sewer have shown that it is possible to submerge the end of the house sewer sufficiently to cause bubbling of air through the water-closet trap and into the dwelling when either the sink or tray compartments is discharged. When the house sewer of the system of figure 10 is submerged 3 inches, no bubbling of either the water-closet or tub traps was observed for any combination of fixture discharge, while with a submergence of 4 inches the results noted occur.

The bubbling observed occurred immediately after the discharge into the stack began, and continued for approximately 1 second. The bubbling of air from the system, through the trap and into the dwelling was not sufficiently violent, with any combination of fixture discharge, to throw water out of the fixture. Although the depth of seal of the water-closet trap was ¾ inch greater than for the bathtub trap, bubbling occurred only through the water-closet trap.

Although an occasional bubbling of sewer gas through the water closet in the amounts and for the durations observed in these tests cannot be considered a health hazard, it is, nevertheless, undesirable that such bubbling occur frequently, and under such conditions it may be considered objectionable on esthetic grounds alone. The frequency with which this phenomenon will occur in practice depends on the frequency and degree of submergence of the house sewer by flow in the street sewer. If the street sewer is not overloaded and has been otherwise properly designed, the submergence of the house sewer will occur only infrequently, if at all, and a stack-vented single-story system consisting of both bathroom and kitchen fixtures will operate satisfactorily. On the other hand, if the street sewer is sufficiently overloaded to cause frequent and severe submergence of the house sewer, objectionable bubbling of sewer gas or air through the stack-vented water closet or tub will result if a sink or combination fixture is connected to a single-story stack above a stack-vented water closet or bathtub.

IX. Corrosion and Fouling

Corrosion and fouling of drains and traps may increase the hydraulic roughness and change the effective diameter of these parts of the drainage system. The drains and traps in a stack-vented system, the corrosion and fouling of which might adversely affect the operation of the system, consist of the bathtub and water-closet traps and drains, the portion of the stack between the stack-vented bathtub or water closet and the combination fixture and lavatory, and the traps and drains of the combination fixture and lavatory.

As indicated in section VIII–7 of this paper, any reduction in diameter of a bathtub or water-closet trap, such as might be caused by corrosion and fouling, could not cause increased trap-seal losses to occur with the test loads adopted here, which gave trap-seal reductions of 1 inch or less with clean and noncorroded traps. Tests were not made to determine the effect of diameter of either the bathtub or water-closet drain. However, comparison of the data in figure 6 for the 3-inch water-closet drain with those in figure 7 for the 1½-inch-diameter bathtub drain will show that no appreciable effect on trap-seal losses should be expected from a decrease in diameter of these fixture drains caused by corrosion and fouling.

As indicated in section VIII–2, any decrease in diameter of the portion of the stack between the water closet and tub drain and the combination-fixture and lavatory drains, owing to corrosion and

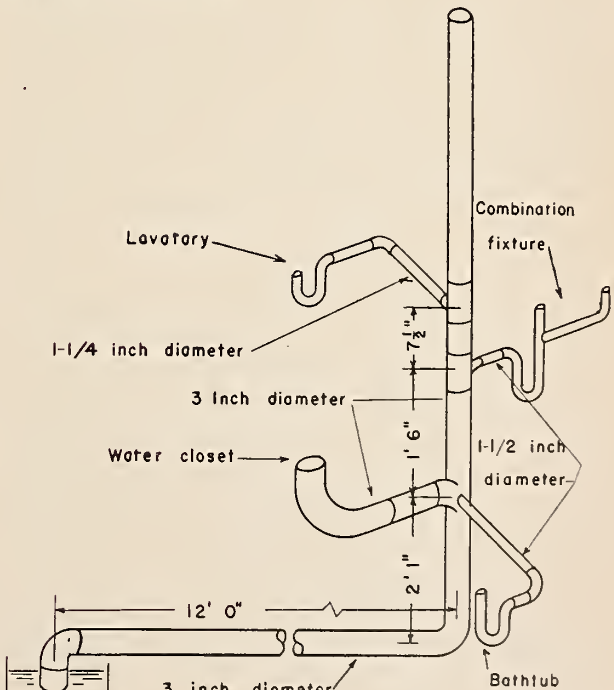

Figure 10. *Test setup for simulating submerged house sewer.*

fouling, will cause increased trap-seal losses for the stack-vented water closet and bathtub. However, this portion of the stack is washed by the relatively clean and nonfouling water of the lavatory, and hence it appears reasonable to assume that whatever fouling occurs in this portion of the stack will not be sufficient to affect trap-seal losses materially.

Corrosion and fouling of the combination-fixture drain or trap presents a more complicated problem. The effect of corrosion and fouling of this drain or trap to any degree will result in a decrease in rate of discharge from the fixture. However, the effect of fouling or caking in the combination-fixture drain at the point where it connects to the stack will also result in a decrease in cross-sectional area at this point, which may cause, under certain circumstances, an increase in velocity of the water entering the stack. The test results previously discussed have shown that a decrease in volume rate of flow into the stack will cause a decrease in trap-seal losses of stack-vented fixtures, while an increase in entrance velocity will cause an increase in trap-seal losses. It is possible, therefore, that while the corrosion and fouling of the combination-fixture drain will cause a decrease in rate of discharge from the fixture, it will also cause an increase in trap-seal losses of the stack-vented water closet and tub.

Consider the combination fixture, its trap, and its drain up to the point where the latter joins the stack. Let H be the total head acting on the system; that is, assuming atmospheric pressure in the stack at the point where the drain connects to the stack, let H be the difference in elevation between the water level in the fixture and the outlet end of its drain to the stack. The head, H, must overcome the pressure drop through the trap, and the pressure drop through the drain and must create the velocity imparted to the water. Therefore, we have the relation

$$H=h_0+h_2+\frac{v_2^2}{2g}, \qquad (6)$$

where

h_0=the sum of the frictional and curvature losses in the trap, the entrance loss occasioned by flow from the fixture into the trap, and the loss due to the change in cross-sectional area, if any, at the point where the trap joins the horizontal drain,

h_2=the pressure head lost through frictional resistance in the drain.

v_2=the velocity of the water in the drain.

The pressure drops, h_0 and h_2, can be related to the velocities and dimensions of the trap and drain through the equations

$$h_0=k\frac{v_0^2}{2g}, \qquad (7)$$

and

$$h_2=f\frac{l}{d_2}\frac{v_2^2}{2g}, \qquad (8)$$

where f is the Darcy-Weisbach friction factor, l and d_2 are, respectively, the length and diameter of the drain, v_0 is the velocity of flow through the trap, and g is the acceleration due to gravity. The quantity k is commonly assumed for simplicity to be a constant as applied to elbows, return bends, and similar pipe fittings, although it actually varies somewhat with the hydraulic roughness of the fitting, the Reynold's number, and the ratio of the bend radius to the diameter of the fitting, and as used in eq 7 it will also vary with the ratio d_0/d_2, where d_0 is the diameter of the trap.

The loss due to change in cross section between the trap and the horizontal drain will be small, for the range of values of d_0 and d_2 in which we are interested, compared to the losses in the trap due to curvature and friction, and it will be assumed for the present that k is a constant as applied to traps.

Substituting the above expressions for h_0 and h_2 in eq 6 and noting that $d_2^2v_2=d_0^2v_0$, we have

$$H=\frac{v_2^2}{2g}\left[k\frac{d_2^4}{d_0^4}+f\frac{l}{d_2}+1\right],$$

and

$$v_2=\sqrt{\frac{2gH}{k\frac{d_2^4}{d_0^4}+f\frac{l}{d_2}+1}},$$

and it follows that the volume rate of flow Q from the fixture is

$$Q=\frac{\pi d_2^2}{4}\sqrt{\frac{2gH}{k\frac{d_2^4}{d_0^4}+f\frac{l}{d_2}+1}}, \qquad (9)$$

Equation 9 makes it possible to compute for the conditions assumed the rate of discharge from a fixture installation in which the trap and fixture drain have been fouled and corroded to various degrees.

It has been shown by the data in figures 8 and 9 that trap-seal losses of stack-vented fixtures increase, for a given stack diameter, as the rate of flow of the combination fixture increases and also, for the range of variables tested here, as the diameter d_2 of the drain of the combination fixture decreases. The data in these figures can be made to fall, approximately at least, on a single curve by plotting h/d_1 against $Q/(d_1^2\sqrt{d_2 g})$, as shown in figures 11 and 12. Consequently, it follows, for the range of the test results reported here, that a decrease in the factor $N=Q/(d_1^2\sqrt{d_2 g})$ will be accompanied, for a given stack diameter, by a decrease in trap-seal losses of stack-vented fixtures.

Substituting for Q, in the expression for N, its value from eq 9, we have

$$N=\frac{\pi\sqrt{2H}}{4d_1^2\sqrt{k\frac{d_2}{d_0^4}+f\frac{l}{d_2^4}+\frac{1}{d_2^3}}}=\frac{\pi\sqrt{2H}}{4d_1^2Y^{1/2}}. \qquad (10)$$

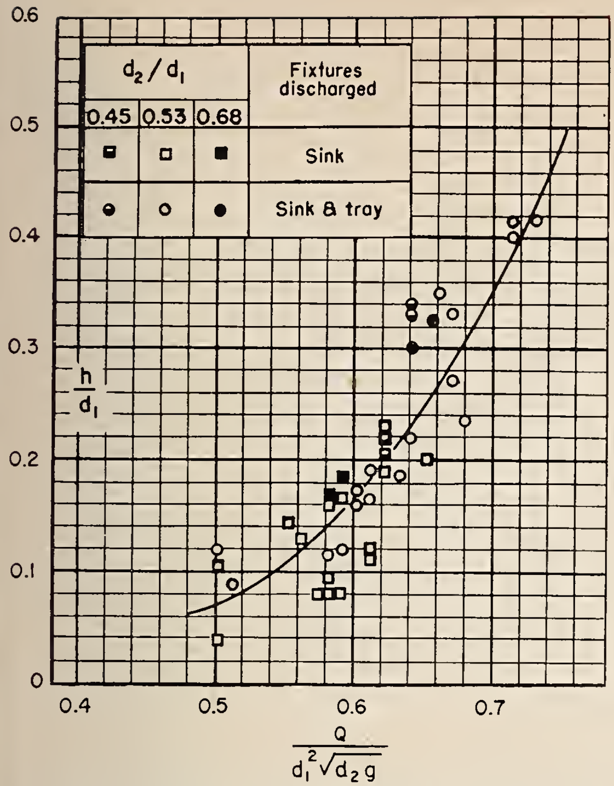

FIGURE 11. *Relative trap-seal losses for a stack-vented water closet.*

Obviously any decrease in d_0 or increase in f due to corrosion or fouling will cause a decrease in N and hence decreased trap-seal losses of stack-vented fixtures. With regard to reduction in the diameter d_2 of the combination-fixture drain, it is apparent that the effect on N will depend on the relative magnitudes of k, d_0, f, l, and d_2, and it is obvious from eq 10 that a decrease in d_2 will more readily cause an increase in N when k is large, and f and l are small.

In practice, the minimum possible length of l is approximately one foot. There are no data available on the value of k for traps, but it appears reasonable to assume that it would not in general exceed three times the value of k for a single 90-degree elbow. The experimental data on the value of k for 90-degree commercial pipe elbows are fragmentary and contradictory. Commonly used values for that portion of k that is due to curvature alone range from 0.75 to 0.90 for elbows. Inasmuch as these values are for screw-pipe elbows in which the diameter of the elbow is greater than that of the pipe, whereas in the case of the bend in a trap there is no such change in cross section, it appears reasonable to assume that the value of k for ordinary plumbing P-traps, which consist essentially of three short 90-degree bends, will not be larger than 3.0 when the traps are clean and uncorroded.

Under the assumption of a trap diameter d_0 of 1⅜ inches, a value of k of 3.0, and a length l of 1 foot, the value of the term $Y=k(d_2/d_0^4)+f(l/d_2^4)+1/d_2^3$ has been plotted against d_2 in figure 13 for various values of the friction factor f. It is apparent from this figure that a decrease in diameter of a nominal 1½-inch-diameter drain owing to corrosion and fouling will result, for a given f, in a decrease in Y and hence in an increase in trap-seal losses only for relatively small reductions in diameter, and that severe reductions in diameter will cause an increase in Y and hence a decrease in trap-seal losses of stack-vented fixtures. It is also apparent that the increase in the friction factor f, which will normally accompany corrosion and fouling, will materially increase Y and hence decrease trap-seal losses.

It has been uniformly found by investigators that corrosion and caking cause an increase in the friction factor f, and relatively minor amounts of corrosion and caking cause a material increase in f. In this connection, Hunter [7, p. 42] estimates that a reduction in new pipe diameter of 0.05 inch will be accompanied by an increase in f from approximately 0.025 to approximately 0.035; and a further decrease in pipe diameter of 0.1 inch will be accompanied with an increase in f to approximately 0.054.

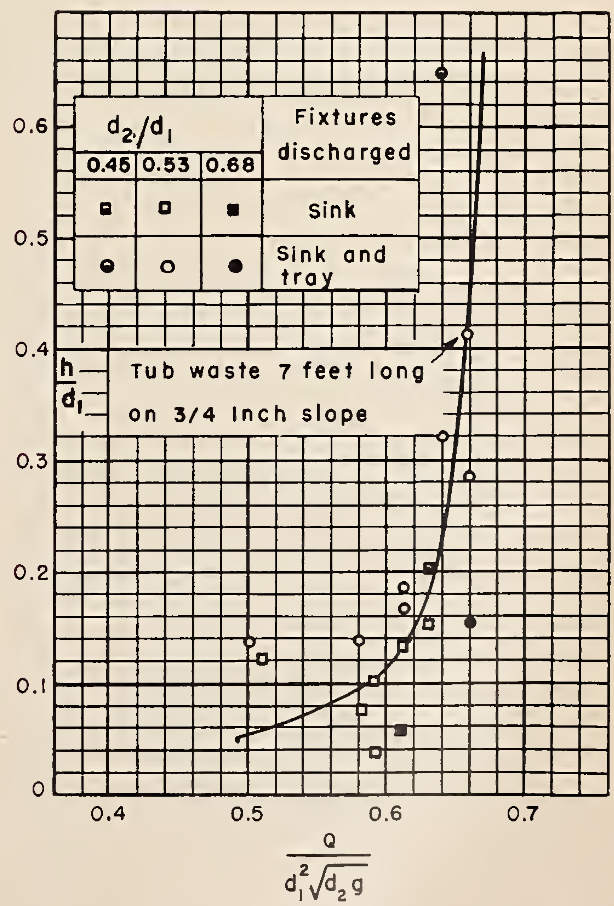

FIGURE 12. *Relative trap-seal losses for a stack-vented bathtub.*

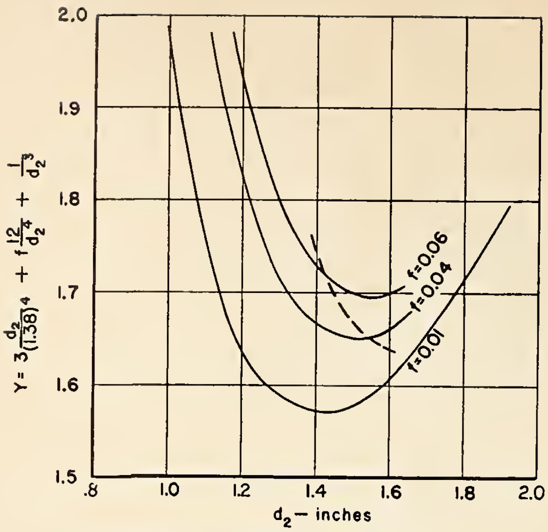

FIGURE 13. *Effect of f and d_1 on Y.*

An increase in Y represents a decrease in trap-seal losses.

The broken curve in figure 13 is based on Hunter's estimate of the relation between the friction factor, f, and the decrease in diameter, d_2, and, if we assume these estimates to be correct, it is apparent that the net effect of corrosion and caking of the drain will be to increase the quantity Y, and hence to decrease the trap-seal loss of stack-vented fixtures.

As has been stated previously, it has been assumed that k is a constant. It has been shown by Beij [8] that k, for 90° bends, increases with an increase in the relative hydraulic roughness of the wall material. As the ordinary plumbing trap is a succession of three such bends, it would be expected that k for traps would also increase with the hydraulic roughness of the trap material. It is clear, therefore, from eq 10 that any corrosion or fouling of the trap which results in an increase in its hydraulic roughness will cause a decrease in N and hence will result in a decrease in the trap-seal losses of stack-vented fixtures connected to the stack below the fixture trap in question.

For the above reasons it would not be expected that the trap-seal losses observed in these tests of stack-vented systems with clean and uncorroded pipes would increase with age.

X. Conclusions

1. A group of stack-vented bathroom fixtures consisting of a water closet, lavatory, and shower stall or bathtub, with or without shower head, will operate satisfactorily under the pressure conditions occurring in a plumbing drainage system, provided that:

(a) The water-closet and tub or shower drains connect to the stack at the same level,

(b) The stack is 3 or more inches in diameter,

(c) No other fixtures connect to the stack at a higher level,

(d) The lengths and slopes of the fixture drains are such that self-siphonage of the fixture traps does not occur.

2. A stack-vented group of fixtures consisting of the fixtures of a single bathroom and a kitchen sink or combination fixture located on the top floor of a multistory system will operate satisfactorily under the pressure conditions occurring in a plumbing drainage system, provided the conditions of conclusion 1 are observed and vented fixtures connect to the stack below the top floor or that the stack or building drain is otherwise vented below that point.

3. A stack-vented group of fixtures, consisting of the fixtures of a single bathroom and a kitchen sink or combination fixture located on the top floor of a system in which no vented fixtures connect to the stack below the top floor, or the building drain is not otherwise vented, will operate satisfactorily under all normal vacuums and positive pressures occurring in the stack, but will be subject to objectionable bubbling of air from the drainage system through the water-closet and bathtub traps when the street sewer is sufficiently overloaded to cause frequent and severe submergence of the outlet end of the house or building sewer.

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