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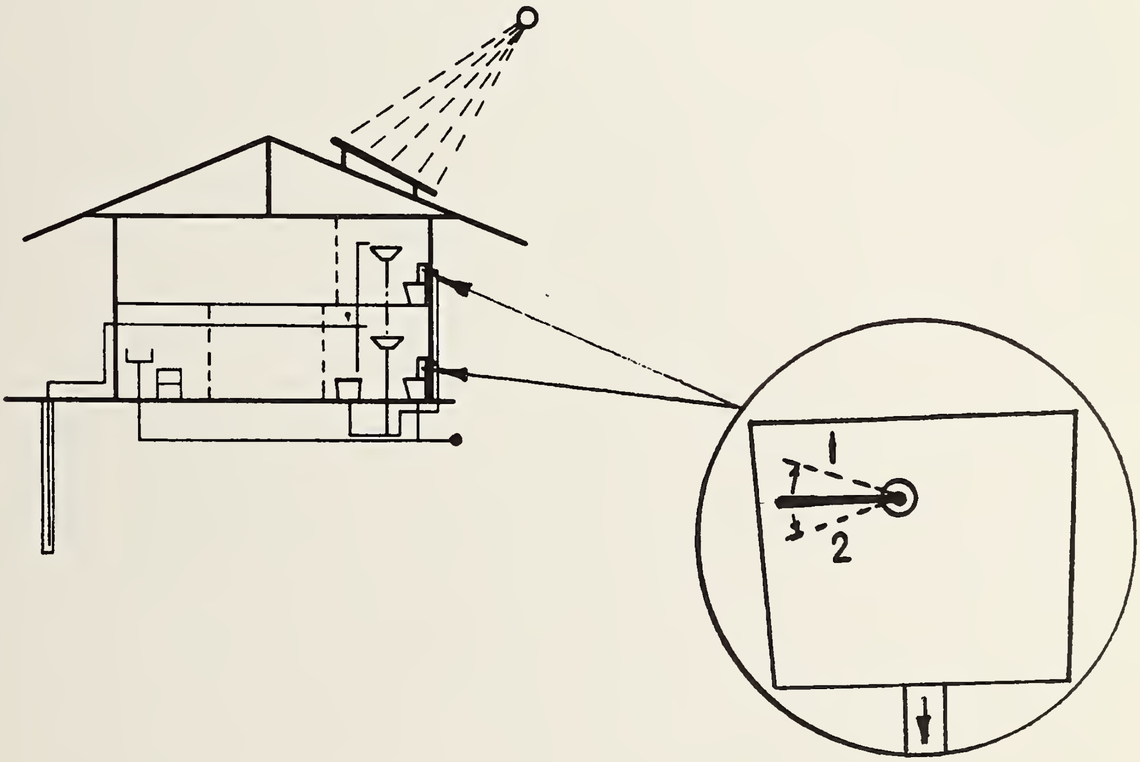
Criteria and Evaluation for Two-Step Flush Devices for Water Closets



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Lawrence S. Galowin

Center for Building Technology
National Engineering Laboratory
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National Bureau of Standards
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PREFACE

This report is one of a group documenting National Bureau of Standards (NBS) research and analysis efforts in developing water conservation test methods, analysis economics and strategies for implementation and acceptance. This work is sponsored by the Department of Housing and Urban Development/Office of Policy Development and Research in the National Bureau of Standards (NBS) Water Conservation projects under HUD Interagency Agreement H-48-78.

Certain trade names and company products are identified in this report. In no case does such identification imply that the products are necessarily the best available for the purpose for which they were mentioned.

ABSTRACT

Laboratory tests of two-step flush control devices for water closets were conducted to provide data and develop test methods for evaluating water saving devices for water closets. Criteria for performance and testing procedures for laboratory testing are recommended for evaluating two-step flush devices for installation in conventional water closets.

Key Words: dual flush toilets; low flush toilets; water conservation; water closets

CRITERIA AND EVALUATION OF TWO-STEP FLUSH DEVICES FOR WATER CLOSETS

1. INTRODUCTION

1.1 Background

Surveys of residential water usage patterns in the United States indicate that the water consumption per capita per day ranges from 150 liters (40 gallons) to 260 liters (70 gallons) [1,2,3]. Most studies indicate that the water closets use from 30 to 45 percent of the total household consumption. Therefore, water conservation measures focus primarily on the water closet for the reduction of the total residential water usage and also for the reduction of the total wastewater influents to the wastewater processing systems. At present, various water conserving toilets are available; they are classified as "zero discharge toilets," such as vacuum toilets and macerator toilets, which require less than one gallon per usage. The major manufacturers market "water saving" toilets which consume 13 liters (3.5 gallons) per flush cycle as compared to the ordinary toilets which require 20 liters (5.5 gallons) per flush cycle. Most water-saving water closets do not have any unique features in comparison to the ordinary toilets. These water closets contain supply tanks which are either smaller or contain flush valves which are designed to deliver a smaller quantity of water to the bowl. Some manufacturers modified the design of the bowl to facilitate a reduction in the water usage. Various techniques have been used in order to reduce the water consumption of the toilets. Well known methods are the bricks and bottles placed in the tank to displace the volume of water that otherwise would have been flushed down. Dams are other well known manufactured devices which are placed in the toilet tank and retain water in the bottom section of the tank from being flushed out.

1.2 Description of Two-Step Flush Devices

The two-step (or multi-step) flush mechanism is a device inserted in the toilet tank and replaces the ordinary flush valve. The device enables the user to selectively operate the toilet tank so that the nominally full quantity of water will be delivered to the bowl or a partial quantity, depending on the choice of the user. Selection between the two quantities of water is made by either having two distinct flush handles or one handle which can be rotated clockwise and counterclockwise so that each handle or direction actuates a different part of the mechanism to control and deliver the desired quantity of water to the bowl. A partial flush cycle is attained by an earlier closure of the flush valve which stops the flow of water to the bowl and retains part of the water in the tank. The design and operation of the devices evaluated in this project are described in Appendix A.

Two-step flush mechanisms have been used in Europe for over four decades and have provided adequate performance. The European flush down toilets ordinarily require 9-10 liters (2.4 - 2.6 gallons) for a full flush and 4.5 - 5.5 liters (1.2 - 1.4 gallons) for the partial flush normally used for the flushing of urine and light solid matter. A survey in England [4] indicated a substantial reduction of water consumption when dual flush devices were used. However, contrary to the European flush down toilets, for which two-step flush devices in siphonic water closet bowls used in this country is less readily applicable. In the United States, the water closet bowls operate on the principle of siphonic action which is more complex as compared to the operation of the European Flush Down toilets which operate by a weir overflow action. The design of a two-step device for siphonic bowls requires additional considerations. The American siphonic bowl consumes large quantities of water. Since this toilet type is still a standard fixture in this country and is expected to remain so in the immediate future, the development of two-step flush devices is highly desirable since they have the potential of a 40 percent saving of the toilet water consumption and 15 percent saving of the total household water consumption. This report presents the results of the investigation and laboratory testing of two-step flush devices. The laboratory work also included tests on siphonic water closets for evaluating their performance for two modes of flush cycles as they are required to be operated when two-step flush devices are installed in the water closet tanks.

1.3 Project Purpose and Objectives

The purpose of this investigation is to establish a basis for objective evaluation of the performance of two-step flush devices designed for the reduction of the water consumption of water closets. The objectives are to develop a methodology, testing procedure, and criteria for evaluating the functional adequacy of two-step flush mechanisms, and recommend the implementation of this material into standards.

1.4 Project Scope

The laboratory work included tests for investigating the effects of reduced water usage such as occur with two-step flush devices on the following aspects:

- Hydraulic operation of the water closet
- Sanitary requirement
- Mechanical functions of the two-step flush mechanism

2. RATIONALE AND FRAMEWORK FOR TESTING TWO-STEP FLUSH DEVICES

The criteria for evaluating the two-step flush devices were established on the basis of existing standards for sanitary fixtures [5, 6, 7, 8, 8], and on a rationale based on the elementary functions which two-step flush systems are designed to perform. These requirements include the following elements:

- Siphonic action
- Retention of the trap seal in the water closet
- Adequate removal of the liquid wastes from the bowl
- Adequate cleansing of the surfaces of the bowl
- Adequate removal of paper wastes from the bowl
- Satisfactory mechanical operation of the mechanism of the two-step flush device

2.1 Hydraulic Requirement - Siphonic Action

The conventional American water closet operates on the principle of siphonic action. The hydraulic operation of the water closet is directly related to its functional performance since the occurrence of a siphonic action in the bowl during the flush cycle is the predominant factor for an adequate performance of the bowl. The flush cycle in a siphonic bowl is described by the following three stages: (see Figures 1 and 2)

Stage 1 - Water flows from the tank and enters the bowl through the rim and jet orifices. At this stage, the mode of flow through the trap and down leg is by weir action as the water overflows the weir crest.

Stage 2 - As the sheet of water flows down the weir, air is carried along, and the bend in the down leg prevents the entrance of new air to the bowl. Partial vacuum is created in the waterway, and a full bore flow takes place in the bowl.

Stage 3 - As supply diminishes, the water level in the bowl drops to nearly the bottom of the trap, air enters the trapway, and the siphon breaks.

H_W in Figure 2 represents the available energy during the weir flow stage (plus a small additional velocity head due to the rim jets flow) and H_S, the available head during the siphon action. H_S is far greater than H_W. Therefore, the flow rate and consequently the cleansing action of the bowl takes place primarily in the second stage, while the flow in the first stage does not contribute to the performance of the bowl, and merely serves for priming the siphon. The second stage requires a relatively large amount of water for maintaining the siphon action and evacuating the contents of the bowl. These observations describe the operation of a siphonic water closet from which the following definition was formulated:

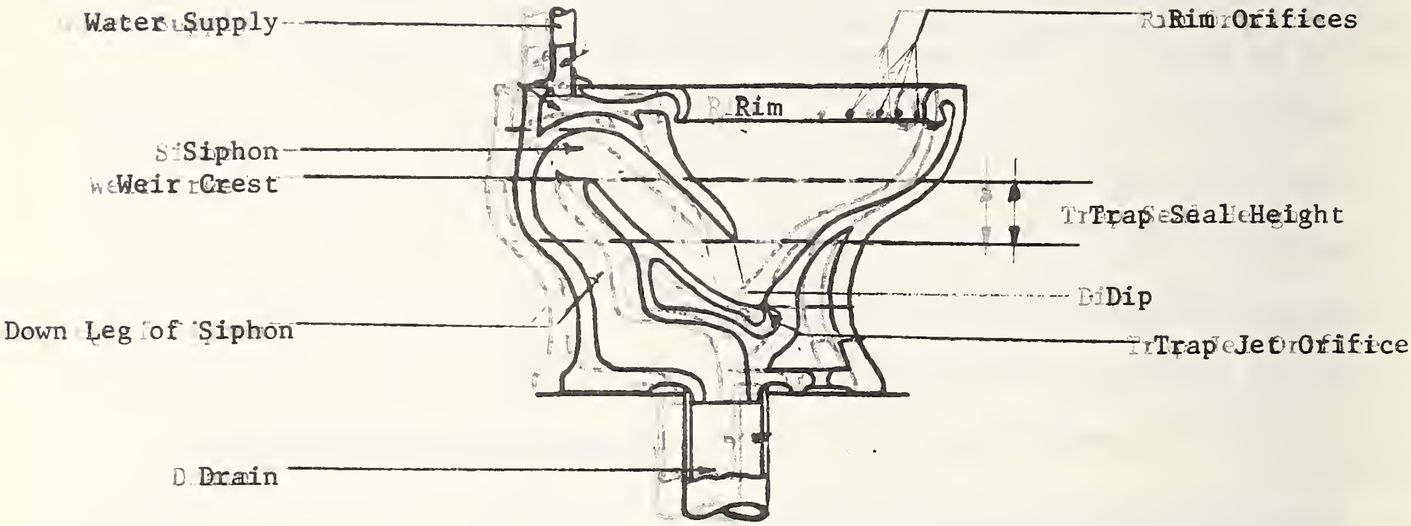


Figure 1. Siphonic water closet bowl

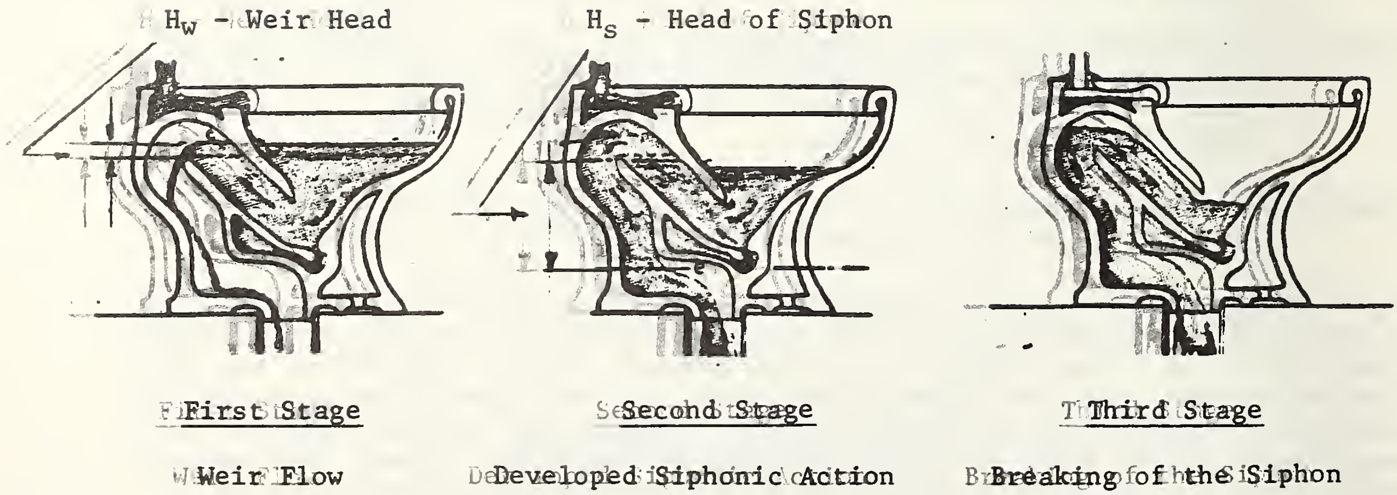


Figure 2. Siphonic action in a siphonic water closet bowl

"A fully developed siphonic action: is that mode of flow in the bowl described in the above three stages, and in the final stage the water level in the bowl drops below the dip of the bowl.

With a reduced quantity of water a "fully developed siphonic action" may not take place in the flush cycle which in turn, may result in a sharp reduction of the performance of the bowl. The tests (described later) indicate that this is indeed the case, and the siphonic action in the bowl is important even for the removal of liquid wastes and light matter such as toilet paper.

2.2 Trap Seal Retention

The function of the trap seal is the prevention of foul air and gases from flowing from the sewer back to the fixtures and the utility room, and is a universal requirement for all sanitary fixtures and appliances. The trap is either an integral part of the fixture or must be connected between the fixture and the drain pipe. For water closets, the requirement for the trap height vary from 50 mm (2 in) to 75 mm (3 in), depending on the water closet type. In reference to the preceding description one notes that the bowl remains nearly empty upon termination of siphonic action. The bowl is refilled by the ball cock through its refill tube which draws part of the water flowing to the tank and directs the water to the bowl. A well-designed refill arrangement is such that the bowl is filled to its weir upon termination of the flush cycle. No water should overflow the weir since any quantity of water overflowing the weir is a waste. A partial flush with a two-step flush mecanism cuts the time of fill and consequently reduces the volume of water refilling the seal trap. It is therefore anticipated that complete replenishment of the seal trap will not always be attained. From a sanitary standpoint, complete restoration of the trap seal is not mandatory since a trap seal level of any magnitude will prevent the backflow of foul gases from the sewer line. However, some minimal trap seal is required as a guard against a complete depletion of the trap because of excessive pressure excursions which may take place in the drains and affect the traps, and because of water evaporation which may take place if the toilet is not being used for a period of several days [9, 10]. A procedure is therefore required to test the integrity of the trap seal when the toilet is flushed with reduced water quantities when two-step flush devices are installed.

2.3 Water Exchange

The incoming water from the tank should replace the contaminated liquid wastes removed from in the bowl. This requirement is important for sanitary and aesthetic reasons. Aesthetically, liquid wastes and residues affecting the clarity of the water in the bowl are undesirable; however, the degree of detection is highly subjective as demonstrated in a limited survey done at the NBS laboratory (see Appendix B, Table 15). It is safely assumed that the "slight" coloration of the bowl is of little importance, and is only secondary to the sanitary aspects. From a sanitary standpoint, residues of liquid wastes are undesirable. Several studies [11, 12] report on bacteriological contamination of plumbing fixtures. Tests on toilets indicate that the degree of contaminants removal is directly dependent upon the quantity of water used in the flush cycle. It is fairly obvious that the more water used per flush, the less residual contaminants remain in the toilet bowl. However, from the health and microbiological point of view, no investigation has demonstrated the correlation between the degree of unflushed contaminants, of any form, in the bowl, i.e. particulates from fecal matter, toilet paper, or urine, to the actual disease transmission by pathogenic organisms. Due to the lack of any medical information, it is difficult to establish the sanitary requirements or determine a "safe" or "critical value" of the contaminants allowed to remain in the bowl after the flush cycle. In the Sixth Draft of ANSI 112.1M-1980 [5], it is stated that "a dilution ratio of at least 100 shall be obtained in each initial flush;" however, it has not been demonstrated whether this value is sufficiently low and safe from the sanitary aspect. The effect of the waste matter residual bacteriological parameters in the bowl is not known and remains to be evaluated by other methods. The objective of this project is to establish a test procedure for determining with a reasonably high degree of accuracy the dilution ratios which occur with reduced quantities of flush water. The improved levels of detection for very small concentration of residuals provide a step forward toward the resolution of the water exchange requirements.

2.4 Rim Wash Test

Unwashed surfaces in the bowl may create, in time, zones of bacterial growth and foul odor. Information on the long-term effects of imperfect rim wash is not available. With reduced flows which occur in partial flush cycles, the effectiveness of the rim wash may be somewhat reduced. However, the purpose of the partial flush cycle is only to remove liquid wastes and "light matter" so that the requirements of the rim wash test for partial flush cycle may be less stringent in comparison to the full flush cycle. Furthermore, since a partial flush cycle will eventually be followed by a full flush cycle, the long-term effects are probably minimal as long as an adequate rim wash is attained with a full flush cycle.

2.5 Paper Removal

Under reduced quantity of flush, it is expected that the water will evacuate the paper load "normally used" after urination. This requirement probably stems from aesthetic reasons, though other liquid excretions soaked in the paper waste may have sanitary hazards. It follows that a test is required to evaluate and, if possible, to quantify the efficiency of the water closet in removing paper wastes under reduced flows.

2.6 Mechanical Performance

Two-step flush devices have not been designed and installed by water closet manufacturers. The devices have been manufactured and marketed by firms which deal with related equipment and devices for sanitary appliances and water conserving devices. As inserts to existing systems, the following needs should be satisfied:

- Compatibility of the device with existing toilets in terms of installation and operation

- Capability in adjusting the controls for the desired quantities of water will be flushed with a sufficient degree of consistency

- Sound construction and durability of parts

- No interference with existing mechanisms

3. TEST METHODS

The following procedures and laboratory test methods were established to evaluate the performance of water closets when modified to function as two-step flush systems by the insertion of the two-step flush devices. The findings of these tests provided information for formulating the test procedures of two-step flush devices.

3.1 Test Samples

Six water closet samples were selected from catalogues of the major manufacturers from types and models most widely used throughout the country. A product search for the two-step devices yielded five systems for evaluation.

For identification purposes, the samples were marked and tested as follows:

Water Closets:

B_1, A_3, A_5, C_3, C_5, K_3

Samples B_1, A_5, C_5 are nominally 5 gallon water closets. Samples A_3, C_3, K_3 are nominally 3 1/2 gallon water saving closets.

Two-Step Flush Devices:

M_1, M_2, M_3, M_4, M_5

Dams:

Dam inserts are intended to reduce the full flush volume discharge per flush cycle. This property was utilyzed for attaining partial flushes to the water closets for simulating the partial flush cycle of two-step flush devices.

3.2 Test Sequence

The following test sequence was carried out for each combination of a water closet:

a. Testing of the water closets with their original flushing mechanisms subjected to the full quantity of flush water.

b. Testing of the water closets with their originl flushing mechanisms subjected to partial quantities of flush water ranging from 40 to 70 percent of the total flush quantity. This range was based on the rationale that with a partial quantity lower than 40 percent adequate performance would probably not be attained, and with a partial quantity higher than 70 percent, the amount of saving would not be significant. The partial flush quantities were attained by inserting the dams into the tanks.

c. Testing of the water closets with the two-step flush mechanisms, applying the full and partial quantities of flush.

Water Supply Pressure Conditions

Each case of the tests sequence a, b, and c was performed subject to the total pressure supply of:

15, 25, 40, and 80 psi. (103, 172, 276, 414, 552 kPa).

3.3 Test Equipment and Apparatus

The equipment and apparatus used for conducting the tests are described in Figure 3. The method for standardizing the flow conditions upstream the water closet under testing was adopted from the procedure proposed by Stevens Institute and incorporated in the revised ANSI A112.19.2 Standard. This procedure is as follows: A standard orifice designed by Davidson Laboratory is connected to the line in place of the water closet ("FO" in Figure 3). Valve V_2 (in Figure 3) is adjusted until a flow of 3-3.5 gpm takes place in the system at a flowing (static) pressure of 8 psi at no flow conditions. The orifice is then removed and the water closet sample under testing is connected to the line. The position of Valve V_2 is remained untouched throughout the testing.

In addition, the following conditions were imposed in the test at the NBS Laboratory: The ballcock in the tanks was adjusted to close at the marked Water Line at static pressure of 30 psi. The drainage system downstream of the sample included a 90°, 3" sanitary elbow followed by a 3" PVC pipe of 8' long. This condition was imposed merely for consistency: however, the effects of the drainage configuration on the performance of the system were not investigated.

3.4 Laboratory Tests

3.4.1 Geometry of the Water Closet Tanks

The following measurements were made not for testing criteria purposes, but, for obtaining data on the design of the tanks:

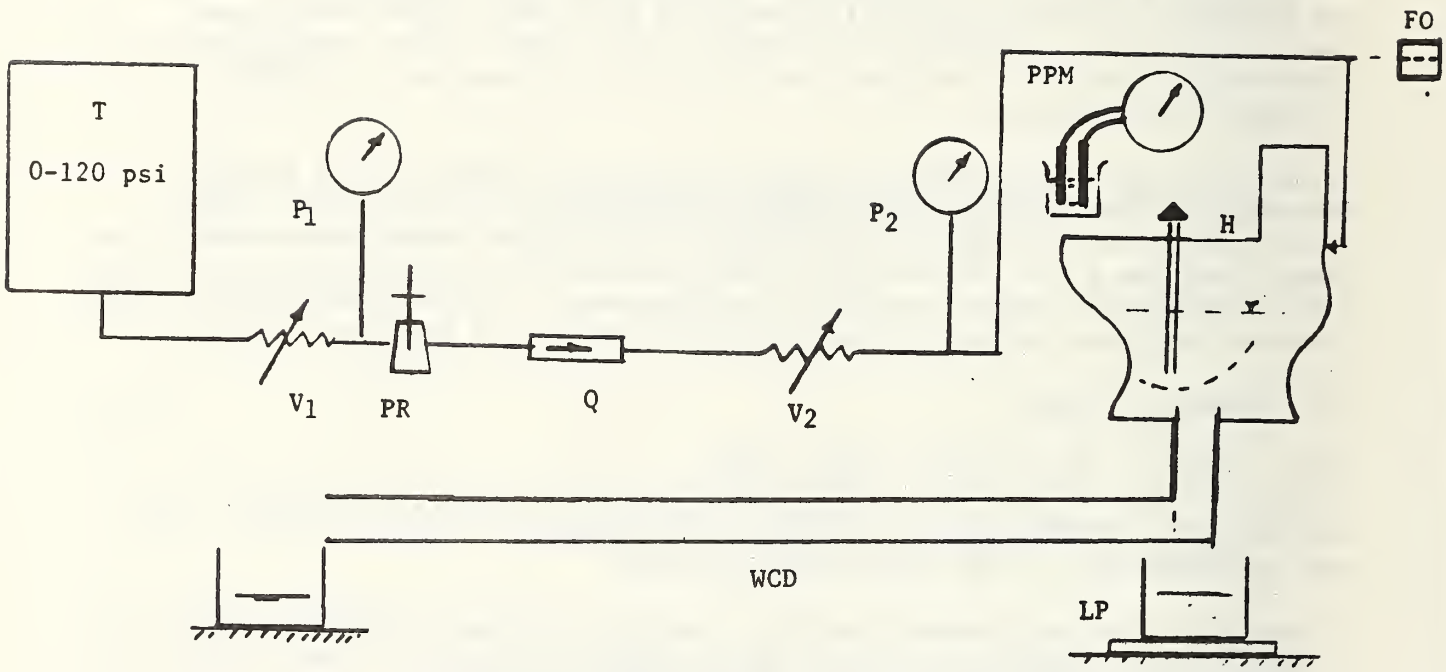
- Establish the relationship between volumetric increments of water from the marked Water Line in the tank to points below and above the Water Line together with the following pertinent parameters:

- The volume of water occupied by the tank up to the Water Line

- The height of the Water Line in reference to the tank bottom

- The overflow level in the tank in reference to the Water Line

These measurements were made by means of a graduated cylinder and a calibrated pressure transducer capable of sensing pressure head differentials as low as 0.1 mm. The transducer was inserted in the tank and the water pressure heads were measured (from an initial datum) as increments of 100 ml of water were added to the tank.



T - Water supply pressure tank, 0-120 psi
P_1, P_2 - Manometers, 0-120 psi
V_1, V_2 - Flow adjusting valves
PR - Pressure reducing valve
Q - Flow totalyzer and flow rate turbine meter
H - Pressure transducer for water level in W.C. indicator
FO - Fixed orifice for test standardization
LP - Load platform (flow rate measurement from W.C.)
PPM - Equipment for Water Exchange, pH/Ion concentration and electrodes
WCD - 3" drain from W.C.

Figure 3. Test equipment and apparatus

3.4.2 Characteristics of Water Closet Bowl

The following measurements were made primarily for classification of the bowl types under study and establishing the geometrical characteristics of the bowls:

- The relationship between the volume increments of water from the bowl's weir level to points going down toward the dip at 2 mm intervals.

- Cross sectional dimensions of the W.C. well at weir level

- Trap Seal Height

- Volume of water in the well up to the weir

- Maximum flow rate from the bowl during the flush cycle.[1]

The relationship between volume and height increments were obtained in a similar manner as described in 5.3.1. With the bowl empty, water was added by predetermined increments, and the corresponding increase in water level was measured by the pressure transducer.

3.4.3 Relationship between the Line Static Pressure and the Flow Rate through the Ball Cock

This test was performed for information on the hydraulic characteristics of the ball cock. The pressure reducing valve was adjusted for obtaining the desired static pressure in the system at no flow conditions. Valve V_1 was then opened and the flow rate and static (flowing) pressure was then recorded.

3.4.4 Water Closet Bowl, Tank and Ball Cock Interaction During a Full Flush Cycle

The following parameters were evaluated as they effect the performance of the bowl and the total water consumption of the water closet bowl:

- Water usage per flush cycle

- Water wasted over the weir through the refill tube during the flush cycle

- Ratio of the maximum refill flow rate to the total maximum flow rate to the tank. This parameter is important from the water economy standpoint as a large ratio may result in wastage of water over the weir in case when the bowl is filled before the water level in the tank reached the water line.

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[1] This information was obtained from Stevens Institute, from test data on water closets of the same type and model evaluated at NBS. It is assumed that the performance of water closets of the same model do not differ appreciably.

- Ratio of the refill flow rate and total flow rate at the instant when the water level in the tank has risen to approximately 1/2" before ball cock closure. This value is measured to observe the distribution of the flow between the tank and the bowl when the ball cock resistance is increased.

The water usage per flush cycle was measured by placing a graduated cylinder under the drain line at the end of the flushing cycle and collecting the excess water flowing over the weir from the time the bowl is filled by the refill tube. The refill flow rate was measured by diverting the flow from the refill tube to a graduated cylinder for a fixed interval of time for obtaining the flow per unit time to the refill tube.

All of the following tests were performed for the full and partial flush quantities of water. Four partial flush quantities were tested which ranged from 40 to 70 percent of the total flush cycle.

3.4.5 Trap Seal Loss and Siphonic Action

The following parameters were evaluated:

- Trap seal loss after the first flush cycle (defined as h_r). The trap seal loss was measured by a pressure transducer which recorded the equivalent drop in static pressure in the bowl.

- Occurrence of siphonic action in the first and second flush cycle. "A fully developed siphonic action" was defined in Article 2.1 and was tested by visual observation.

- If siphonic action did not take place in the second flush cycle, the parameter V_c defined as the minimum quantity of water required for adding to the bowl for attaining siphonic action, was evaluated.

- If siphonic action takes place for two consecutive flush cycles the test continued with two additional flush cycles for testing whether siphonic action takes place for four consecutive flush cycles.

Test Procedure

The tests were performed for the full and partial flush cycles for five nominal line pressures of 15, 25, 40, 60 and 80 psi (103, 172, 276, 414, 552 kPa).

Step 1. With the tank filled and the water in the bowl full to the weir a flush cycle was initiated and the following data recorded:

- Maximum ball cock flow rate in the flush cycle. Measured by the turbine flow meter.

- Ball cock static pressure at maximum flow rate.

- Total flow in the flush cycle. Measured by the turbine flow totalyzer (turbine meter)

- Adequate siphonic action (denoted by yes or no)

- Trap seal depletion in height

- Trap seal depletion in volume obtained from the data of the geometry of the bowl.

If siphonic action occurred in the first flush cycle, the testing proceded to step 2; otherwise no further testing was made.

Step 2. Step 1 was repeated retaining the water in the well from the previous flush. If siphonic action took place, Step 3 was performed. If siphonic action did not take place, the following steps were carried out.

The bowl was filled and the handle tripped for a partial flush cycle. One hundred ml of water were added to the well and tested for siphonic action. If siphonic action did not take place, the bowl was refilled, flushed again and 200 ml added. This sequence was repeated with another increment of 100 ml until siphonic action took place. The water volume required to replenish the depleted well to create a siphonic action in the next flush cycle was defined as "critical volume" and denoted by Vcr.

Step 3. With the water in the well in the state which occurred in the second flush cycle, two more flushes were made to determine whether siphonic action takes place for four successive flushes.

The Granule Test

The granule test as specified in the revised ANSI A112.19.2 Standard (Article 7.4.3.2) is intended for testing the performance of the bowl in its removal of slurry material. The test medium is 100 ml of disc-shaped polyethylene granules 2-3 mm in diameter and a thickness of 1.5 mm. The granules are inserted into the bowl, and the water closet is flushed. The criterion for passing the test is that "not more than 125 (5%) shall be visible in the well after each initial flush."

The interest in applying this test for the partial flush cycle was primarily for seeing whether the granule test may serve as a means for quantifying the test of siphonic action. The test was therefore applied for the full and partial flush cycles.

3.4.6 Water Exchange Test

The water exchange was evaluated by the value of the "relative concentration ratio" defined as a ratio of the concentration of liquid contaminants in the bowl after usage of the water closet and the residues after flushing. For partial flush cycles this test was performed twice. In the first time, the bowl was tested with its well full to the weir with fresh water. In the second time, the bowl was tested as left from the first time, namely, with residues in the well and no water was added to replenish the trap seal. The relative concentration ratio was calculated as follows:

$$R_1 = \frac{C_{q1} - C_b}{C_{i1} - C_b} ; \qquad R_2 = \frac{C_{q2} - C_b}{C_{i2} - C_b}$$

where:

C_b is the background concentration of contaminants in the bowl

C_{i1} is the initial concentration of simulated contaminants before flushing the water closet

C_{q1} Concentration of the residues of the simulated contaminants after the flush cycle

C_{i2} is the intitial liquid waste concentration resulting from liquid wastes which remained from the previous flush cycle and a new load of simulated contaminants

C_{q2} is the final concentration after the second flush cycle

In the initial tests, the medium was sodium chloride from which a solution of 4 percent (by weight) was prepared and the test load constituted 200 ml of that solution which was inserted in the bowl prior to flushing. There was no intent to simulate the actual sodium chloride concentration which normally occurs in liquid wastes.[1] This relatively high concentration of the test medium was used to reduce errors in the measurements of small concentration which may occur after the flushing cycle.[2] In the course of fthe initial testing, it was found that the background concentration of chlorides is in the range of 15-30 parts per million (ppm) and the errors in measuring these values is in the range of the values which occur in the tests. The test medium was therefore switched to sodium bromide (NaBr). Sodium bromide is completely soluble in the range of the concentration used and its concentration in the water supply is less than 0.05 ppm. Thus, higher accuracy was attained, in addition, the frequency for checking the background concentration was appreciably reduced.

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1 The urine from an adult for a 24-hour period is 1,500 ml at a total common salt content of 15 grams. This probably amounts to an average single load of 200 ml at 2 percent NaCl concentration [15].

2 Table 17 in Appendix B indicates the level of residues (C_q) as obtained with four levels of loads (C_i). As observed the values of "R" are nearly identical for all test loads. These results show that this test method is reproducible, furthermore, "R" is independent of the initial value C_i. However, as C_q is reduced (to 5 ppm) the relative errors are increased, and the larger the C_i value, the smaller the errors in C_q.

Test Procedures

a. Equipment

Numerous instruments are available for measuring ion concentrations in salt solutions. The laboratory equipment used in these experiments was: (These items listed below could be replaced by many typically similar devices).

- Fisher Model 750 pH meter
- Bromide ion electrode (No. 9417) manufactured by Orion
- Reference electrode (No. 9970) manufactured by Orion
- Sodium bromide salt in crystal form
- Standard (1 mole) bromide solution

The Fisher Model 750 instrument enables measuring concentrations (in ppm) directly by its built-in microprocessor. Prior to testing, two samples of known concentrations are read in the instrument and the calibration curve is internally generated for direct reading of the sodium bromide concentration in ppm units.

b. Measurement of Sample Concentrations and the Evaluation of "R".

Step 1. Measures background concentration C_b of sodium bromide. This value was assumed as constant throughout the day's work.

Test medium: 200 ml of 4 percent by weight of bromides (51.5 grams of sodium bromide per 1000 ml of water).

Step 2. With water in the bowl full to the weir, the test medium was inserted and thoroughly mixed (with a stirring rod). Two samples were taken from the bowl and their concentration measured. The mean concentration of the samples represented the value C_{i1}.

Step 3. The toilet was flushed, the water in the bowl thoroughly mixed again and two samples were taken from the bowl. Their mean concentration was represented by the value C_{qi}. Also measured were the total flow in the flush cycle and the volume of water in the well.

Step 4. The value of $R_1 = (C_{q1} - C_b)/(C_{i1} - C_b)$ was then computed.

Step 5. When partial flush quantities were tested, steps 2 and 3 are repeated except that the toilet is flushed with the water level in the well remaining unchanged from step 3. The occurrence of siphonic action was recorded. The value $R_2 = (C_{q2} - C_b)/(C_{i2} - C_b)$ was computed.

3.4.7 Test of Paper Removal

A "normal test load" of toilet paper was assumed to be in the range of six to twelve double strips approximately 4 1/2 x 4 1/2" of commercially manufactured toilet paper. The test was conducted with six double strips (six pairs) cut from the toilet paper roll and then repeated with twelve double strips after complete bowl refill.

The following procedure was carried out for the partial flush quantities of water:

With the well full to its weir, the test load was inserted in the bowl, allowed to soak and the flushing handle tripped for a partial flush cycle. The number of strips of paper which remained in the bowl were counted. The observation of the occurrence of siphonic action was also recorded.

If at least one strip of paper remained in the bowl, the test was discontinued. If all the toilet paper was removed, another test load was placed in the bowl, without replenishing the trap seal and the test was repeated.

3.4.8 The Rim Wash Test

The purpose of the Rim Wash Test is to test whether the fresh water from the toilet tank reaches all the possibly fouled exposed areas in the bowl. Therefore, a test medium is required whose properties are such that it is washed away when water reaches it, and provides a basis for measurement by:

- Elimination of subjective judgment

- Repeatability of results

- Simplicity of preparation of the medium

- Possibility for quantification and rating of the results

Several test evaluation methods which were considered and tried:

1. The Saw-Dust Test

The "saw dust test" is used in foreign standards [8] for testing the capability of the water closet bowl in washing all the exposed areas of the bowl. The test entails spreading saw dust particles on the surface of the bowl and observing the bowl after the termination of the flush cycle. It is generally required that no traces of saw dust will remain on the surfaces. The preparation of this test medium and the testing procedure are simple. However, the outcome of this test cannot readily be reduced to a quantified measurement since the residues of the saw dust, i.e., density distribution of areas, or weight of particles remaining on the bowl cannot be readily determined. Furthermore, it is difficult to establish a pass/fail criterion for evaluating regions with small amounts of remaining residues, unless the requirement for passing is a total removal of saw dust particles.

2. Chemical Methods

The pH of the water in the tank was raised to relatively large values [8, 9, 10] by inserting sodium hydroxide pellets in the toilet tank. PH indicators were distributed in the bowl for the detection of the basidity of the incoming rim wash so that the areas which were washed by the incoming water changed color and the areas where water was not reached remained unchenged.

The detection of the basic water was made by the following two methods:

a. Pasting pH strip indicators around the circumference of the bowl spaced at various intervals.

b. Coating the bowl with a solution containing phenollihelene (by brushing) such that the areas on which water from the tank reached turned pink and the other areas remained white.

Method "a" yielded distinct and reproducible results; it was, however, discounted because it required a relatively long time for preparation. Method "b" was easy to prepare; however, it did not yield results which could be easily interpreted without resorting to subjective judgment, i.e., the areas reached by the basic water from the toilet tank could not always be easily identified from the areas where water from the tank did not reach the bowl.

3. Marking of Dots and Lines - Paint Test

Marking the bowl surface with artists water color paints applied as test media in dots or line patterns. The research teams of Stevens Institute of Technology in their search for test methods for the rim wash tests conceived this method. Experiments with two methods were evaluated (a) Marking four horizontal lines of approximately 1/8" in width around the inner circumference of the bowl. These lines were spaced 1/2 to 3/4 inch apart starting 3/4 inch from the rim and going down with the fourth line 1/2 inch above the water in the well. (b) Dots of approximately 1/4 inch in diameter were marked in the bowl, spaced 1/2 inch horizontally and vertically.

Dots as test media have an advantage over lines as unwashed areas are indicated by counting discrete points as compared to the measuring lengths of unwashed line segments. A uniform method for drawing the dots on the water closets was provided by preparing paper stensils with a fixed arrangement holes so that the dots could be placed in a consistent manner on the bowl. The stencils were taped to the bowl and painted; upon removal, the dots remained on the water closet surface area. The flushing mechanism was then actuated and the water flowing from the tank washed away the markings. The total length of unwashed lines was then measured for Method (a) and the total number of unwashed dots was counted for Method (b).

In successive tests of identical input conditions, marking four lines and painting dots proved to the reasonably reproducible. Preparation of the test medium however proved to be rather cumbersome and time-consuming. It was, therefore, decided to test the water closet samples in accordance with the procedures outlined in the revised ANSI A112.19.2 Standard as follows:

Test Medium. A fine tipped, felt pen containing a dark colored, water soluble ink.

Procedure. The flushing surface is scrubbed clean with commercial scouring powder to remove any buildup or deposits on the walls. The surface is then rinsed and dried with oil-free air.

An ink line is drawn around the circumference of the flushing surface at a level one inch below the rim jets of the bowl.

The flush release device shall be tripped and the line observed during and after the flush.

When the flushing cycle is completed (tank completely refilled or flushometer cycle completed and trap refill water delivery completed), the lengths of the unwashed line segments where the ink may have remained on the flushing surface is measured and also recorded are approximate positions in the bowl.

This test was performed four times for each test case (partial flush quantity and water supply line pressure).

3.4.9 Additional Tests of the Two-Step Flush Devices

3.4.9.1 Mechanical Evaluation

The following mechanical evaluation was made by visual inspection and manual manipulation of the devices:

- Ease of installation of the device into the tank

- Compatibility of the device with existing mechanisms and parts in the water closet tank

3.4.9.2 Watertightness of Flush Valve

Each device was installed in the tank of all the water closet samples. The tank was filled from the water supply line assembly. The flush valve was tested for leakage during the tank fill cycle and after termination of fill.

3.4.9.3 Consistency in Delivering Fixed Partial and Full Quantities of Water

Each device was tested by measuring the quantity of water delivered for the full and partial flush cycle, for five consecutive flushes.

4. DISCUSSION OF THE LABORATORY TEST RESULTS

The development of criteria and testing procedures are based upon a set of principles which must be considered:

- The basic operational functions and performance requirements which the product must meet.

- The present state of the available manufactured products and their capabilities in terms of meeting these requirements.

- Formulation of the simplest possible test specifications whose test outcome reflect the performance of the product. The purpose of the tests conducted was: (a) to provide a basis for establishing the performance requirements for two-step flush devices, (b) determine the practicability of the various tests and measurements, (c) assess their feasibility to determine performance levels.

The water closet samples chosen for these tests are the most commonly used in the country so that the conclusions drawn from the test data are reasonably general.

4.1 Characteristics of Water Closets

The laboratory tests were limited to six water closets from four manufacturers. These samples showed the variability in the characteristics of water closets.

Table 1 and Figures 4 and 5 illustrated these findings, from which the following variations among the systems may be observed:

- Trap seal height

- Volume of trap

- Dimensions of the bowl water surface

- Hydraulic characteristics of the ball cock

- The flow rate from the bowl

The geometry of the trapway, which is an important parameter, could not be evaluated as this requires cutting the bowl to measure its internal dimensions. The samples contain two water closet groups. A_3, CR_3, and K_3 are water conservation models and B_1, A_5, and CR_5 are conventional 5-gallon water closets. The pairs (A_3, A_5) and (CR_3, CR_5) have identical bowls. In the case of the first pair, the only modification was made in the flapper valve control for delivering a smaller quantity of water per flush. In the second pair, the water saving model has a tank of a smaller volume.

Parameter	Water Closet Samples Tested											
	A_3		CR_3		K_3		B_1		A_5		CR_5	
Trap seal height	85 mm	3.4 in	79 mm	3.1 in	91 mm	3.6 in	102 mm	4.0 in	85 mm	3.4 in	79 mm	3.1 in
Volume of trap	4.20 ℓ	1.1 gal	4.12 ℓ	1.09 gal	3.68 ℓ	0.97 gal	4.84 ℓ	1.28 gal	4.20 ℓ	1.11 gal	4.12 ℓ	1.09 gal
Dimensions of bowl water surface	320 x 305 mm	12.5 x 12 in	295 x 255 mm	11.5 x 10 in	305 x 255 mm	12 x 10 in	305 x 280 mm	12 x 12 in	320 x 305 mm	12.5 x 12 in	295 x 255 mm	11.5 x 10 in
Ball cock flow rate at 15-80 psi range	6.6-15.6 ℓpm	1.74-4.12 gpm	7.1-16.9 ℓpm	1.87-4.46 gpm	6.4-16.2 ℓpm	1.69-4.27 gpm	4.5-20.9 ℓpm	1.18-5.51 gpm	6.6-15.6 ℓpm	1.74-4.12 gpm	2.0-4.7 ℓpm	0.59-1.24 gpm
Ratio of refill to total ball cock flow	0.23		0.05		0.036		0.22		0.23		0.05	
Range of water usage for 15-80 psi	14.7-16.4 ℓpm	3.9-4.3 gal	12.2-14.6 ℓ	3.2-3.9 gal	11.4-14.8 ℓ	3.0-3.9 gal	14.7-18.8 ℓ	4.0-5.0 gal	17.3-20.2 ℓ	4.6-5.3 gal	15.0-21.2 ℓ	4.0-5.6 gal
Maximum flow rate from bowl	106 ℓpm	28 gpm	9 ℓpm	24 gpm	68 ℓm	18 gpm	128 ℓ	34 gpm	106 ℓpm	28 gpm	90 ℓpm	24 gpm
Weir over flow range for 15-80 psi	0.7-0.8 ℓ	0.2 gal	0.70-0.40 ℓ	0.2-0.4 gal	0.20-1.20 ℓ	0.05-0.3 gal	0.60-0.95 ℓ	0.2-0.3 gal	2.3-3.2 ℓ	0.6-0.7 gal	1.1-3.0 ℓ	0.3-0.8 gal

- A_3, CR_3 and K_3 are "water conservation water closet systems.
- The bowls of A_3 and A_5 are identical, so are the bowls CR_3 and CR_5.

Table 1. Characteristics of Water Closet Bowls

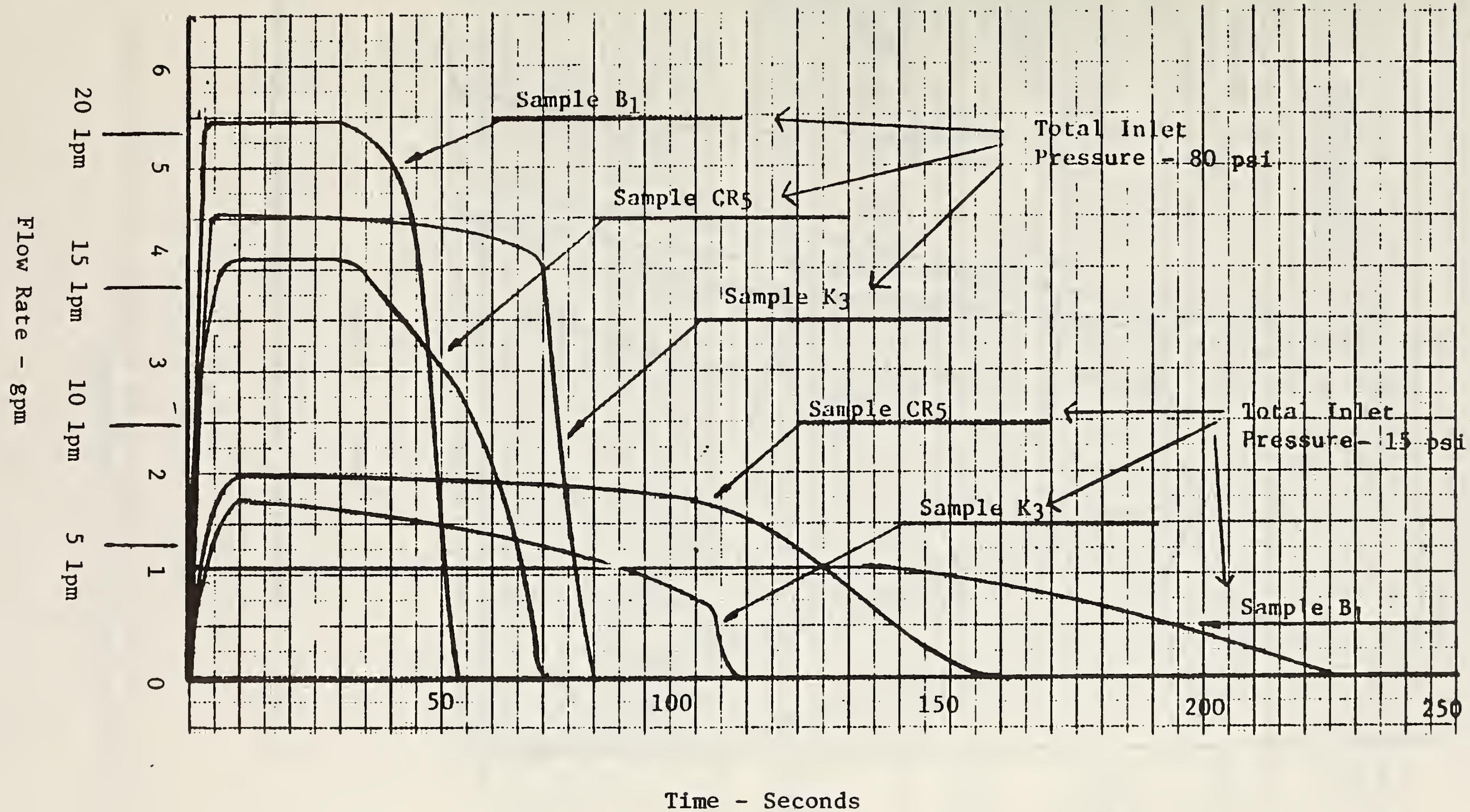

Figure 4. Ball cock flow rate to the tank in time for three w.c. samples for two pressure conditions

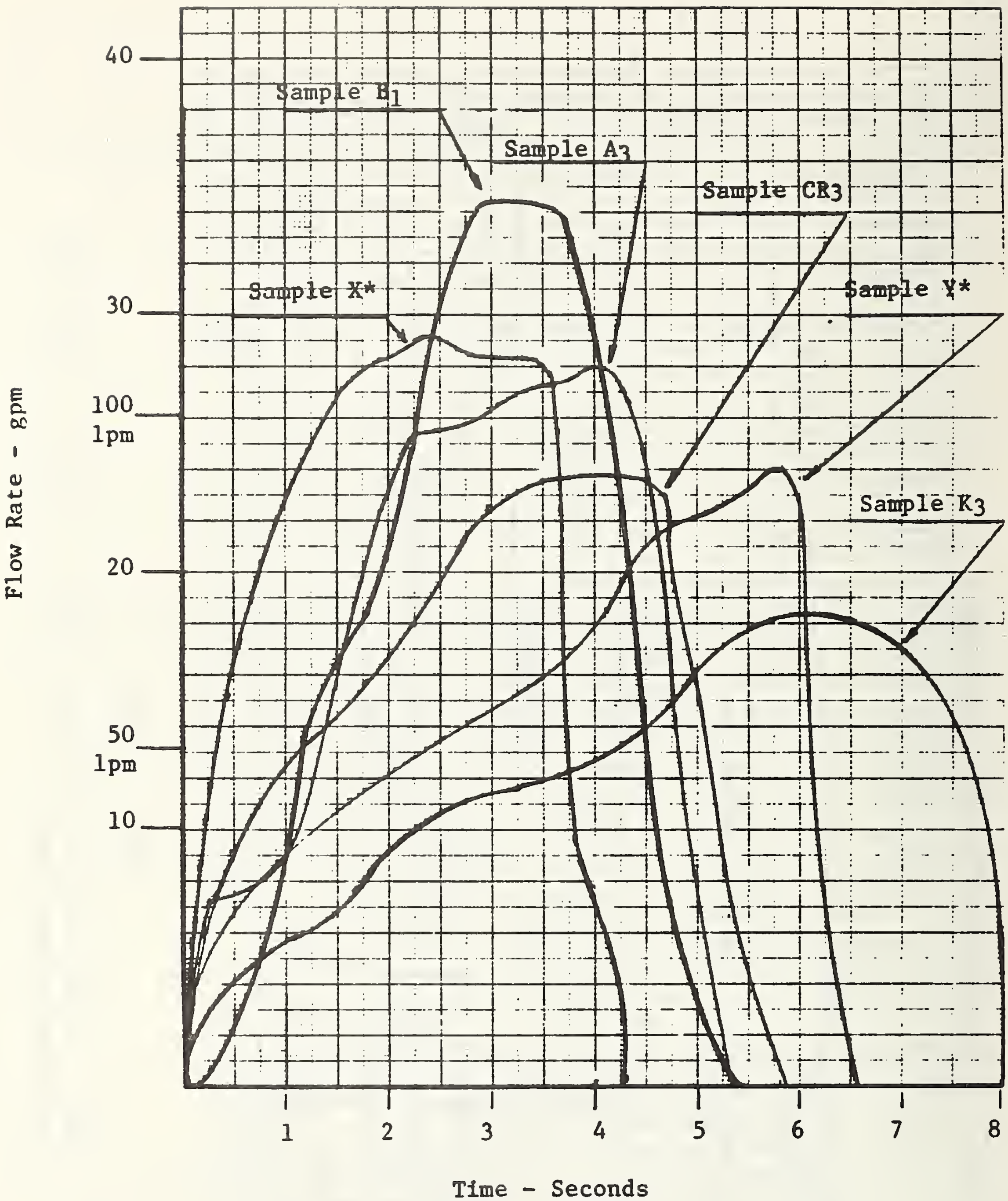

Figure 5. Water flow rate for various water closet bowls

*Samples X and Y were not included in the program - these data were supplied by Stevens Institute of Technology.

4.2 Tests of Siphonic Action and Trap Seal Retention

The tests showed that "a fully developed siphonic action" as defined in Article 4.1 is an important criterion for the evaluation of the performance of the water closet bowl. A siphonic action is essential for an adequate water exchange and the removal of paper wastes (as discussed in Sections 4.3 and 4.4).

Considering the use of a two-step flush mechanism, the following situations may occur:

a. No siphonic action takes place for the full flush cycle even if the water in the well prior to flushing is filled to the weir.

b. Siphonic action occurs when the full quantity is flushed, when the water in the well is full to the weir, but no siphonic action occurs when the trap seal volume is reduced from the previous flush cycle.

c. Siphonic action at all times for the full-flush cycles, even with depleted well, but no siphonic action with partial flush cycles.

d. Siphonic action for the partial flush quantity only when the water in the well is full to the weir.

e. When partial quantities are flushed consecutively, a reduction of the water in the well increases from flush cycle to flush cycle and eventually siphonic action does not take place.

Tables 2a through 2f and Table 3 illustrate these cases in the water closets tested. Among the parameters described in Tables 2a through 2f, V_{cr} is of significant importance. Since it shows when siphonic action did not occur and indicates the volume of water required to add to the depleted trap in the bowl to affect a siphonic action. Table 3 describes the behavior of the bowl for successive partial flush cycles. As the water in the well is gradually reduced at some point, siphonic action no longer appears to take place. This is due to the fact that some quantity of water which was designed to contribute to the siphonic action is used instead for filling the bowl and priming the siphon.

Sample: B_1

Table 2a. Test for syphonic action and trap seal retention

P		Q_{max}	Vf	Vw	WL3				WL0				WL1				WL2			
					Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr
PSI.	KPa	Lpm	lit	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit
15	103	4.5	14.7	0.95	10.2	0.70	9	0	8.9	1.20	15	0.60	7.8	1.55	21	1.10	6.5	1.90	21	1.90
25	172	8.3	15.2	0.60	10.4	1.10	14	0	9.5	1.50	20	0.90	8.2	1.70	24	1.20	6.9	2.15	29	2.00
40	276	12.5	16.1	0.50	11.2	1.05	13	0	10.0	1.65	23	0	8.7	1.80	25	0.90	7.5	2.20	33	1.80
60	414	17.2	17.5	0.45	12.2	0.90	12	0	11.0	1.30	17	0	9.6	1.70	24	0.40	8.4	2.15	29	1.20
80	552	20.9	18.8	0.60	13.3	0.60	8	0	12.1	1.10	14	0	10.7	1.55	21	0	9.4	1.97	28	0.30

WL_3, WL_0, WL_1, WL_2 - Configurations for partial quantities of flush
P_T - Statis pressure (total)
Q_{max} - Maxinum flow rate to tank
Vf - Total water passed in a full flush cycle
V_w - Water wasted over the weir in a full flush cycle
V_p - Total water passed in a partial flush cycle
V_r - Volume of water required to refill well after the flush cycle
h_r - Trap seal height reduction after the flush cycle
Vcr - Volume of water required to replenish the depleted trap for obraining syphonic action.
* indicates that syphonic action took place in the second partial flush cycle and there was no need to add water to the well.

Table 2b. Test for syphonic action and trap seal retention

Sample: A5

P		Qmax	Vf	Vw	WL3				WL0				WL1				WL2			
					Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr
PSL	KPa	Lpm	lit	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit
15	103	6.6	17.3	2.25					14.2	-	-	0	13.0	-	-	0	11.6	-	-	0
25	172	8.5	17.4	2.40					14.8	-	-	0	13.3	-	-	0	12.3	-	-	0
40	276	11.0	18.2	2.50					15.8	-	-	0	14.5	-	-	0	13.2	-	-	0
60	414	13.6	19.2	3.15					17.1	-	-	0	15.9	-	-	0	14.4	-	-	0
80	552	15.6	20.2	3.20					18.6	-	-	0	17.4	-	-	0	15.8	-	-	0

WL_3, WL_0, WL_1, WL_2 - Configurations for partial quantities of flush
P_T - Statis pressure (total)
Q_{max} - Maxinum flow rate to tank
Vf - Total water passed in a full flush cycle
V_w - Water wasted over the weir in a full flush cycle
V_p - Total water passed in a partial flush cycle
V_r - Volume of water required to refill well after the flush cycle
h_r - Trap seal height reduction after the flush cycle
Vcr - Volume of water required to replenish the depleted trap for obraining syphonic action.
* indicates that syphonic action took place in the second partial flush cycle and there was no need to add water to the well.

Sample: CR_5

Table 2c. Test for syphonic action and trap seal retention

P		Q_{max}	Vf	Vw	WL3				WL0				WL1				WL2			
					Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr
PSL	KPa	Lpm	lit	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit
15	103	2.0	15.0	1.05					10.1	0.85	13	0	8.5	0.70	11	0.75	7.3	No syphonic action		
25	172	2.5	15.6	0.90					10.7	1.00	16	0	8.9	1.35	12	0.80	7.1	No syphonic action		
40	276	3.1	17.6	2.20					13.3	-		0	11.3	-	-	0	7.8	1.45	23	0.60
60	414	3.9	19.2	2.35					14.4	-		0	12.5	-	-	0	10.0	0.35	5	0
80	552	4.7	21.2	2.95					15.7	-		0	13.4	-	-	0	10.8	-	-	0

WL_3, WL_0, WL_1, WL_2 - Configurations for partial quantities of flush
P_T - Statis pressure (total)
Q_{max} - Maxinum flow rate to tank
Vf - Total water passed in a full flush cycle
V_w - Water wasted over the weir in a full flush cycle
V_p - Total water passed in a partial flush cycle
V_r - Volume of water required to refill well after the flush cycle
h_r - Trap seal height reduction after the flush cycle
Vcr - Volume of water required to replenish the depleted trap for obraining syphonic action.
* indicates that syphonic action took place in the second partial flush cycle and there was no need to add water to the well.

Table 2d. Test for syphonic action and trap seal retention

Sample: CR_3

P		Q_{max}	Vf	Vw	WL_3				WL_0				WL_1				WL_2			
					Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr
PSL	KPa	Lpm	lit	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit
15	103	7.1	12.2	0.70	7.8	No syp	honic	action	7.0	No syp	honic	action								
25	172	9.4	12.6	0.80	7.0	0.55	9	0	5.9	No syp	honic	action								
40	276	12.0	12.6	0.60	9.3	0.30	5	0	7.8	0.95	13									
60	414	15.0	13.7	1.00	10.5	-	0	0	12.5	0.70	10									
80	552	16.9	14.6	1.40	11.0	-	0	0	15.3	0.50	7									

WL_3, WL_0, WL_1, WL_2 - Configurations for partial quantities of flush
P_T - Statis pressure (total)
Q_{max} - Maxinum flow rate to tank
Vf - Total water passed in a full flush cycle
V_w - Water wasted over the weir in a full flush cycle
V_p - Total water passed in a partial flush cycle
V_r - Volume of water required to refill well after the flush cycle
h_r - Trap seal height reduction after the flush cycle
Vcr - Volume of water required to replenish the depleted trap for obraining syphonic action.
* indicates that syphonic action took place in the second partial flush cycle and there was no need to add water to the well.

Table 2e. Test for syphonic action and trap seal retention

Sample A_3

P		Q_{max}	Vf	Vw	WL3				WL0				WL1				WL2			
					Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr
PSL	KPa	Lpm	lit	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit
15	103	6.6	14.7	0.70	12.3	-	-	0	11.7	-	-	0	9.4	0.6	6	0.4	8.2	0.25	8	0.70
25	172	8.5	15.0	0.45	12.6	-	-	0	12.3	-	-	0	9.8	0.6	6	0	9.0	0.80	6	0.60
40	276	11.0	15.3	0.40	13.5	-	-	0	13.2	-	-	0	10.5	0.1	1	0	8.9	0.50	6	0.60
60	414	13.6	15.5	0.45	14.7	-	-	0	14.5	-	-	0	11.7	-	-	0	9.9	0.20	-	0
80	552	15.6	16.4	0.75	15.9	-	-	0	15.8	-	-	0	12.9	-	-	0	11.0	-	-	0

WL_3, WL_0, WL_1, WL_2 - Configurations for partial quantities of flush
P_T - Statis pressure (total)
Q_{max} - Maxinum flow rate to tank
Vf - Total water passed in a full flush cycle
V_w - Water wasted over the weir in a full flush cycle
V_p - Total water passed in a partial flush cycle
V_r - Volume of water required to refill well after the flush cycle
h_r - Trap seal height reduction after the flush cycle
Vcr - Volume of water required to replenish the depleted trap for obraining syphonic action.
* indicates that syphonic action took place in the second partial flush cycle and there was no need to add water to the well.

Test 2f. Test for syphonic action and trap seal retention

Sample: K_3

P		Q_{max}	Vf	Vw	WL3				WL0				WL1				WL2			
					Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr	Vp	Vr	hr	Vcr
PSL	KPa	Lpm	lit	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit	lit	lit	mm	lit
15	103	6.4	11.4	0.15	-	No syp	hnoic	action	No sy	phonic	acti	on	No sy	phonic	acti	on	No syp	honic	actio	n
25	172	8.7	12.1	0.45	-	No syph	onic	action	No sy	phonic	acti	on	No sy	phonic	acti	on	No syp	honic	actio	n
40	276	11.4	12.2	0.55	6.9	1.50	23	1.20	No sy	phonic	acti	on	No sy	phonic	acti	on	No syp	honic	actio	n
60	414	14.3	13.9	0.77	7.9	1.30	19	0.40	No sy	phonic	acti	on	No sy	phonic	acti	on	No syp	honic	actio	n
80	552	16.2	14.8	1.20	8.3	1.00	13	0.20	No sy	phonic	acti	on	No sy	phonic	acti	on	No syp	honic	actio	n

WL_3, WL_0, WL_1, WL_2 - Configurations for partial quantities of flush
P_T - Statis pressure (total)
Q_{max} - Maxinum flow rate to tank
Vf - Total water passed in a full flush cycle
V_w - Water wasted over the weir in a full flush cycle
V_p - Total water passed in a partial flush cycle
V_r - Volume of water required to refill well after the flush cycle
h_r - Trap seal height reduction after the flush cycle
Vcr - Volume of water required to replenish the depleted trap for obraining syphonic action.
* indicates that syphonic action took place in the second partial flush cycle and there was no need to add water to the well.

Table 3. Occurrence of siphonic action for successive applications of partial flush cycle

W.C. Sample: B_1

For successive flush cycles:
y - indicates that siphonic action occurred.
n - indicates that siphonic action did not take place.

Case: WL3

Volume Cycle flow ℓ	1st	2nd	3rd	4th
10.2	y	y	n	
10.4	y	y	y	n
11.2	y	y	y	y
12.2	y	y	y	y
13.3	y	y	y	y

Case: WL0

Volume Cycle flow ℓ	1st	2nd	3rd	4th
8.9	y	n		
9.5	y	n		
10.0	y	y	n	
11.0	y	y	y	n
12.1	y	y	y	y

Case: WL1

Volume Cycle flow ℓ	1st	2nd	3rd	4th
7.8	y	n		
8.2	y	n		
8.7	y	n		
9.6	y	n		

Case: WL2

Volume Cycle flow ℓ	1st	2nd	3rd	4th
6.5	y	n		
6.9	y	n		
7.5	y	n		
8.4	y	n		
9.4				

Table 4 illustrates cases for which siphonic action did not take place and provides the values of V_p, V_{cr}, and $V_p + V_{cr}$. V_p is the total water usage for the partial flush cycle and V_{cr} the add water to the bowl required for siphonic action. $V_p + V_r$ signify the total water required to attain siphonic action.

Table 4. Values of V_p and V_{cr} for Two W.C. Samples

V_p	V_c	V_p & V_{cr}	V_p	V_c	V_p & V_{cr}
8.9	0.4	9.5	9.4	0.4	9.8
9.5	0.9	10.4	8.2	0.7	8.9
7.8	1.1	8.8	9.0	0.6	9.6
8.2	1.2	9.4	8.9	0.6	9.5
8.7	0.9	9.6			
9.6	0.4	10.0			
6.5	1.9	8.4			
6.9	2.0	8.9			
7.5	1.8	9.3			
8.4	1.2	9.6			
9.4	0.3	9.7			

As noted from Table 5, the values for $V_p + V_{cr}$ are nearly constant in the range of 8.9-10.5 liters (2.4-2.7 gallons). The practical aspect of the value for V_{cr} is that it indicates the change of the refill required in order that siphonic action will take place for the particular partial flush cycle.

Returning to the five possible cases ("a" through "e") which may occur in a partial and a full flush cycle, the following conclusions may be drawn:

Cases "a" and "b" should be considered a failure as the device interfers with the normal operation of the toilet for the full quantity of flush water.

Case "c" is not desirable as no siphonic action takes place in the partial flush cycle.

Cases "d" and "e" are marginal, as siphonic action does not take place all the times for the partial quantity of flush. As discussed in Articles 6.3 and 6.4, the performance of the bowl is strongly dependent upon an adequate siphonic action. With the assumption that a full flush cycle will eventually be used, a failure for obtaining a siphonic action after several consecutive partial flush cycles may be tolerable.

Therefore, a reasonable requirement may be formulated as follows:

- Siphonic action is required for the full flush quantity of water at all times.

- Siphonic action is required for the partial flush quantity, at least, for three consecutive flushes.

As observed from the limited data, these requirements imply that the water usage per partial flush cycle is at least 10 liters as indicated by the tests performed.

Trap Seal Retention

Partial-flush cycles nearly always cause a depletion of the trap seal levels since the refill time is reduced and a smaller water quantity is delivered to the bowl. Tables 2a - 2f illustrate the depletion of the trap seals in the water closet samples when tested for the partial flush cycles. This depletion of the trap may be prevented with the ball cock refill flow rate is increased; however, any increase of the refill flow rate will cause an excessive weir overflow for the full flush cycles. However, taking into considerations performance requirements for household drainage systems as cited in codes [13], the following requirements may be formulated:

"The reduction in the water closet trap seal height after any flush cycle shall not exceed 25 mm (1 in)."

The Granule Test

The "Granule Test" as specified in the revised ANSI A112.19.2 Standard was applied to evaluate the removal of slurries. The intent of this test was not to simulate any aspect of the functional performance of the water closet bowl under partial flush conditions, but to observe whether this test may serve as means for quantifying the siphonic action in the water closet bowl. Table 5 summarizes the test results for one sample tested. As would be expected, when no siphonic action takes place, most granules are not flushed and remain in the bowl. When siphonic action takes place, at least 90 percent of the granules are flushed down the toilets. This test would not be recommended for testing two-step flush devices, since the test for siphonic action provides a more reliable information on the hydraulic performance of the water closet.

4.3 Water Exchange Test

Water exchange test was included in the revised ANSI A112.19.2 Standard. The test medium is a standard dye solution from which several comparator samples of varied concentrations are prepared. The dye solution is inserted into the W.C. bowl and flushed. The dye concentration of the residue in the bowl is determined by visual comparison against the comparator samples. The revised ANSI Standard specifies that "a dilution ratio of at least 100 shall be obtained in each initial flush." This comparative test for evaluating the residue of the contaminants in the bowl after flushing is relatively simple and inexpensive. In anticipation of future needs for a more accurate evaluation for the water exchange process in the bowl, particularly as low flow water closets may be acceptable, other test methods were sought.

Table 5. Granule test results for partial flush cycle

The granule test was performed as specified in the revised ANSI 112.19.2M Standard:

100 ml of polyethelene granules 2-3 mm in diameter are placed in the bowl's well and the toilet tank flushed. The number of granules remaining in the bowl are counted or weighed.

Case: WL3

Volume Cycle Flow ℓ	1st Flush Cycle 1	2	3	Mean	2nd Flush Cycle 1	2	3	Mean	Siphonic Action
10.2	51	40	44	45	33	42	60	45	yes
10.4	29	22	35	27	13	7	33	18	yes
11.2	12	9	11	10	9	12	12	10	yes
12.2	9	6	7	8	8	11	6	8	yes
13.3	10	13	7	10	11	9	10	9	yes

Case: WL0

Volume Cycle Flow ℓ	1st Flush Cycle 1	2	3	Mean	2nd Flush Cycle 1	2	3	Mean	Siphonic Action
8.9	65	81	95	80	All	90 ml	90 ml	93 ml	no
9.5	35	35	36	35	74	150	125	117	yes
10.0	22	16	19	19	18	12	21	17	yes
11.0	20	22	12	18	12	17	23	17	yes
12.1	13	13	14	13	9	16	20	15	yes

Case: WL1

Volume Cycle Flow ℓ	1st Flush Cycle 1	2	3	Mean	2nd Flush Cycle 1	2	3	Mean	Siphonic Action
7.8	46	75	60	60	All	All	All	All	no
8.2	30	44	40	38	All	All	All	All	no
8.7	34	32	28	31	90 ml	90 ml	90 ml	90 ml	no
9.6	24	22	20	22	110	120	160	130	yes
10.7	17	21	23	20	40	26	18	28	yes

Case: WL2

Volume Cycle Flow ℓ	1	2	3	Mean	1	2	3	Mean	Siphonic Action
6.5	87	90	99	93	All	All	All	All	no
6.9	55	81	71	69	All	All	All	All	no
7.5	41	32	41	38	All	All	All	All	no
8.4	20	23	26	23	All	All	All	All	no
9.4	27	28	17	24	All	All	All	All	no

As described in Section 5.4.6, the parameter used for the evaluation of the water exchange was the "relative concentration ratio" defined as the residues of the contaminants after flushing the bowl divided by the level of contaminants before flushing, where it has been assumed that a substance can be placed in the water closet for simulation purposes. For a test medium, any water soluble substance can be used as long as an instrument is available for measuring to a reasonable accuracy a range of concentrations of 1/10 to 1/10000.[1] Several test media have been used in the past by various researchers. Brunel University [14] used sodium permanganate as medium to evaluate the water exchange of European water closet bowls. The parameter measured was the "optical density" from which the dye concentrations are derived. The Standards Institute of Israel [15, 16] used sodium chloride for a test medium. The concentrations were evaluated by titration with a solution of silver nitrate ($AgNO_3$) and the use of potassium chromate ($KCrO_4$) as an indicator.

In addition to the test procedure specified in the revised ANSI A112.19.2 which was proposed by Stevens Institute, the dye dilutions were evaluated at Stevens Institute by a fluormeter which measures the relative light intensities and converted by a calibration function to concentrations. As described in Article 3.2.3, the test medium used at the National Bureau of Standards' laboratory was sodium bromide. Eventually, all these methods should be compared and evaluated in terms of their simplicity, required time of preparation, testing time, and accuracy.

Test Results

Tables 6a through 6f and Figure 6 describe the relationship between the relative concentration ratios and the total flow in the flush cycle for the water exchange test on one of the W.C. samples. A sharp increase of "R" takes place with the reduction of the total inflow to the W.C. bowl. R_2 represents the values for the corresponding partial quantities flushed the second time. As observed, siphonic action strongly affects the level of residues remaining after flushing the bowl. In the absence of an adequate siphonic action, an appreciable portion of the liquid contaminants may not be flushed from the bowl. Siphonic action was attained for partial flush cycles of 10 liters and the values of "R" did not exceed 0.05. In accordance with the requirement of the ANSI A112 Standard values over 0.01 would not pass the test. Table 7 indicates the results of water exchange test conducted with European wash down water closets. The values of the relative concentration are in most cases appreciably smaller. In addition, a good water exchange can be attained with volumes as low as 4 liters. The reason may be attributed to the fact that evacuation of the water from the european bowls is by weir action and a large portion of the water in the well flow out by an apparent piston action. In addition, the volume of water in the well for European water closets is only half as much as the volume for siphonic water closets.

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1 See Appendix A for test accuracy analysis.

Table 6a. Concentration ratios of sodium bromide in the w.c. well, before and after flushing

Test medium: 200 ml. of 4% sodium bromide (NaBr)

R_1 - Concentration ratio in the first flush
R_2 - Concentration ratio in the second flush
V - Water inflow to the W.C.
W - Water in the W.C. well in the second flush
P - Statis pressure in psi
Syphonic Action - Denotes whether syphonic action took place in the second flush cycle

$R_1 - (C_{i1} - C_b)/Cq1 - C_b)$
$R_2 - (C_{i2} - C_b)/C_{q2} - C_b)$
Where:
"C" denotes NaBr concentrations in ppm as follows:
C_b - Background concentrations
C_{i1} - Before first flush
C_{q1} - After first flush
C_{i2} - Before second flush
C_{q2} - After second flush

Sample: B_1

Water Exchange Test

Flush	P	V inflow gal.	V inflow lit.	W W.C. gal	W W.C. lit.	R_1	R_2	Syphonic Action
Partial	15	1.87	7.08	0.774	2.93	0.102	0.497	no
Quant.	25	1.97	7.49	0.708	2.68	0.090	0.438	no
1	40	2.12	8.02	0.692	2.62	0.070	0.377	no
(WL_2)	60	2.35	8.89	0.708	2.68	0.047	0.284	no
	80	2.62	9.91	0.626	2.37	0.038	0.056	yes
Partial	15	2.13	8.06	0.869	3.29	0.065	0.422	no
Quant.	25	2.19	8.29	0.829	3.14	0.065	0.384	no
2	40	2.34	8.86	0.808	3.06	0.052	0.298	no
(WL_1)	60	2.55	9.65	0.824	3.12	0.039	0.064	yes
	80	2.87	10.86	0.875	3.31	0.026	0.035	yes
Partial	15	2.49	9.42	0.967	3.66	0.024	0.071	no
Quant.	25	2.58	9.77	0.888	3.36	0.033	0.049	yes
3	40	2.75	10.41	0.845	3.20	0.027	0.038	yes
(WL_0)	60	2.97	11.24	0.941	3.56	0.021	0.031	yes
	80	3.25	12.30	0.991	3.75	0.016	0.016	yes
Partial	15	2.67	10.11	1.089	4.12	0.030	0.049	yes
Quant.	25	2.77	10.48	0.988	3.74	0.025	0.031	yes
4	40	2.96	11.20	1.001	3.79	0.018	0.025	yes
(WL_3)	60	3.24	12.26	1.041	3.94	0.014	0.018	yes
	80	3.57	13.51	1.118	4.23	0.0078	0.010	yes
Full	15	3.85	14.57	1.279	4.84	0.0072		
Quant.	25	3.96	14.99	1.279	4.84	0.0051		
	40	4.18	15.82	1.279	4.84	0.0030		
	60	4.48	16.96	1.279	4.84	0.0013		
	80	4.87	18.43	1.279	4.84	0.0005		

Table 6b. Concentration ratios of sodium bromide in the w.c. well, before and after flushing

Test medium: 200 ml. of 4% sodium bromide (NaBr)

R_1 - Concentration ratio in the first flush
R_2 - Concentration ratio in the second flush
V - Water inflow to the W.C.
W - Water in the W.C. well in the second flush
P - Statis pressure in psi
Syphonic Action - Denotes whether syphonic action took place in the second flush cycle

$R_1 - (C_{i1} - C_b)/Cq1 - C_b)$
$R_2 - (C_{i2} - C_b)/C_{q2} - C_b)$
Where:
"C" denotes NaBr concentrations in ppm as follows:
C_b - Background concentrations
C_{i1} - Before first flush
C_{q1} - After first flush
C_{i2} - Before second flush
C_{q2} - After second flush

Sample: A5

Water Exchange Test

Flush	P	V inflow gal.	V inflow lit.	W W.C. gal	W W.C. lit.	R_1	R_2	Syphonic Action
Partial	15	3.07	11.63	1.11	4.20	0.017	0.014	yes
Quant.	25	3.04	11.52	1.11	4.20	0.012	0.013	yes
1	40	3.21	12.16	1.11	4.20	0.011	0.0099	yes
(WL_2)	60	3.54	13.42	1.11	4.20	0.0062	0.0068	yes
	80	3.86	14.63	1.11	4.20	0.0028	0.0028	yes
Partial	15	3.45	13.08	1.11	4.20	0.0089	0.0057	yes
Quant.	25	3.61	13.68	1.11	4.20	0.0039	0.0044	yes
2	40	3.87	14.67	1.11	4.20	0.0031	0.0028	yes
(WL_1)	60	4.25	16.10	1.11	4.20	0.00094	0.0012	yes
	80	4.62	17.51	1.11	4.20	0.00043	0.00016	yes
Partial	15	3.86	14.63	1.11		0.0030	0.0043	yes
Quant.	25	4.02	15.24	1.11		0.0025	0.0037	yes
3	40	4.20	15.92	1.11		0.0022	0.0033	yes
(WL_0)	60	4.56	17.28	1.11		0.00040	0.00058	yes
	80	4.99	18.91	1.11		0.00026	0.00040	yes
Partial	15	-						
Quant.	25	-						
4	40	-						
(WL_3)	60	-						
	80	-						
Full	15	4.59	17.40	1.11		0.00013		
Quant.	25	4.73	17.93	1.11		0.00026		
	40	4.72	17.89	1.11		0.00006		
	60	5.04	19.10	1.11		0.00010		
	80							

Table 6c. Concentration ratios of sodium bromide in the w.c. well, before and after flushing

Test medium: 200 ml. of 4% sodium bromide (NaBr)

R_1 - Concentration ratio in the first flush
R_2 - Concentration ratio in the second flush
V - Water inflow to the W.C.
W - Water in the W.C. well in the second flush
P - Statis pressure in psi
Syphonic Action - Denotes whether syphonic action took place in the second flush cycle

R_1 - $(C_{i1} - C_b)/Cq1 - C_b)$
R_2 - $(C_{i2} - C_b)/C_{q2} - C_b)$
Where:
"C" denotes NaBr concentrations in ppm as follows:
C_b - Background concentrations
C_{i1} - Before first flush
C_{q1} - After first flush
C_{i2} - Before second flush
C_{q2} - After second flush

Sample: CR_5

Water Exchange Test

Flush	P	V inflow gal.	V inflow lit.	W W.C. gal	W W.C. lit.	R_1	R_2	Syphonic Action
Partial	15							
Quant.	25							
1	40	2.32	8.78	.698	2.64	.0506	.0938	no
(WL_2)	60	2.69	10.18	.993	3.76	.0296	.0333	yes
	80	2.88	10.90	1.088	4.12	.0255	.0276	yes
Partial	15	2.30	8.70	.890	3.37	.0494	.0644	yes
Quant.	25	2.30	8.70	.731	2.77	.0613	.1213	no
2	40	2.92	11.05	1.088	4.12	.0224	.0311	yes
(WL_1)	60	3.23	12.23	1.088	4.12	.0206	.0215	yes
	80	3.46	13.10	1.088	4.12	.0135	.0102	yes
Partial	15	2.53	9.57	.865	3.27	.0447	.0378	yes
Quant.	25	2.69	10.18	.818	3.10	.0497	.0421	yes
3	40	3.38	12.79	1.088	4.12	.0168	.0161	yes
(WL_0)	60	3.63	13.74	1.088	4.12	.0102	.0095	yes
	80	4.00	15.14	1.088	4.12	.0060	.0063	yes
Partial	15							
Quant.	25							
4	40							
(WL_3)	60							
	80							
Full	15	3.55	13.44	1.088	4.12	.0154		yes
Quant.	25	3.83	14.50	1.088	4.12	.0094		yes
	40	4.39	16.62	1.088	4.12	.0019		yes
	60	4.77	18.05	1.088	4.12	.0003		yes
	80	5.29	20.02	1.088	4.12	.0002		yes

Table 6d. Concentration ratios of sodium bromide in the w.c. well, before and after flushing

Test medium: 200 ml. of 4% sodium bromide (NaBr)

R_1 - Concentration ratio in the first flush
R_2 - Concentration ratio in the second flush
V - Water inflow to the W.C.
W - Water in the W.C. well in the second flush
P - Statis pressure in psi
Syphonic Action - Denotes whether syphonic action took place in the second flush cycle

$R_1 = (C_{i1} - C_b)/(C_{q1} - C_b)$
$R_2 = (C_{i2} - C_b)/(C_{q2} - C_b)$
Where:
"C" denotes NaBr concentrations in ppm as follows:
C_b - Background concentrations
C_{i1} - Before first flush
C_{q1} - After first flush
C_{i2} - Before second flush
C_{q2} - After second flush

Sample: CR_3

Water Exchange Test

Flush	P	V inflow gal.	V inflow lit.	W W.C. gal	W W.C. lit.	R_1	R_2	Syphonic Action
Partial	15							
Quant.	25							
1	40							
(WL_2)	60							
	80							
Partial	15							
Quant.	25							
2	40							
(WL_1)	60							
	80							
Partial	15							
Quant.	25							
3	40							
(WL_0)	60	2.25	8.52	.906	3.43	.0467	.0971	no
	80	2.51	9.50	.957	3.62	.0337	.0444	yes
Partial	15							
Quant.	25	1.98	7.49	.568	2.14	.0706	.1034	no
4	40	2.39	9.05	1.011	3.82	.0501	.0278	yes
(WL_3)	60	2.60	9.84	1.088	4.12	.0440	.0381	yes
	80	2.88	10.90	1.088	4.12	.0223	.0310	yes
Full	15	3.01	11.39	1.088	4.12	.0182		
Quant.	25	3.06	11.58	1.088	4.12	.0190		
	40	3.39	12.83	1.088	4.12	.0108		
	60	3.66	13.85	1.088	4.12	.0103		
	80	3.89	14.72	1.088	4.12	.0053		

Table 6e. Concentration ratios of sodium bromide in the w.c. well, before and after flushing

Test medium: 200 ml. of 4% sodium bromide (NaBr)

R_1 - Concentration ratio in the first flush
R_2 - Concentration ratio in the second flush
V - Water inflow to the W.C.
W - Water in the W.C. well in the second flush
P - Statis pressure in psi
Syphonic Action - Denotes whether syphonic action took place in the second flush cycle

R_1 - $(C_{i1} - C_b)/Cq1 - C_b)$
R_2 - $(C_{i2} - C_b)/C_{q2} - C_b)$
Where:
"C" denotes NaBr concentrations in ppm as follows:
C_b - Background concentrations
C_{i1} - Before first flush
C_{q1} - After first flush
C_{i2} - Before second flush
C_{q2} - After second flush

Sample: A3

Water Exchange Test

Flush	P	V inflow gal.	V inflow lit.	W W.C. gal	W W.C. lit.	R_1	R_2	Syphonic Action
Partial	15	-	-	-	-	-	-	-
Quant.	25	2.22	8.41	0.898	3.40	0.026	0.197	no
1	40	2.36	8.94	0.999	3.79	0.033	0.167	no
(WL_2)	60	2.63	9.97	1.001	3.80	0.021	0.023	yes
	80	2.92	11.07	1.110	4.21	0.015	0.016	yes
Partial	15	2.49	9.44	0.954	3.62	0.033	0.073	no
Quant.	25	2.58	9.78	0.941	3.57	0.024	0.121	no
2	40	2.75	10.42	1.091	4.13	0.018	0.012	yes
(WL_1)	60	3.07	11.64	1.110	4.21	0.013	0.010	yes
	80	3.37	12.77	1.110	4.21	0.0076	0.0097	yes
Partial	15	3.07	11.64	1.110	4.21	0.017	0.014	yes
Quant.	25	3.04	11.52	1.110	4.21	0.012	0.013	yes
3	40	3.22	12.20	1.110	4.21	0.011	0.0098	yes
(WL_0)	60	3.54	13.41	1.110	4.21	0.0061	0.0068	yes
	80	3.86	14.63	1.110	4.21	0.0028	0.0028	yes
Partial	15	3.12	11.82	1.110	4.21	0.0064	0.0080	yes
Quant.	25	3.28	12.43	1.110	4.21	0.0042	0.0068	yes
4	40	3.53	13.38	1.110	4.21	0.0044	0.0034	yes
(WL_3)	60	3.80	14.40	1.110	4.21	0.0021	0.0022	yes
	80	4.16	15.76	1.110	4.21	0.00091	0.0011	yes
Full	15	4.41	16.71	1.110	4.21	0.00053		
Quant.	25	3.78	14.33	1.110	4.21	0.0022		
	40	3.85	14.59	1.110	4.21	0.0022		
	60	4.07	15.43	1.110	4.21	0.0015		
	80	4.28	16.22	1.110	4.21	0.00064		

Table 6f. Concentration ratios of sodium bromide in the w.c. well, before and after flushing

Test medium: 200 ml. of 4% sodium bromide (NaBr)

R_1 - Concentration ratio in the first flush
R_2 - Concentration ratio in the second flush
V - Water inflow to the W.C.
W - Water in the W.C. well in the second flush
P - Statis pressure in psi
Syphonic Action - Denotes whether syphonic action took place in the second flush cycle

$R_1 - (C_{i1} - C_b)/Cq1 - C_b)$
$R_2 - (C_{i2} - C_b)/C_{q2} - C_b)$
Where:
"C" denotes NaBr concentrations in ppm as follows:
C_b - Background concentrations
C_{i1} - Before first flush
C_{q1} - After first flush
C_{i2} - Before second flush
C_{q2} - After second flush

Sample: K_3

Water Exchange Test

Flush	P	V inflow		W W.C.		R_1	R_2	Syphonic Action
		gal.	lit.	gal	lit.			
Partial	15							
Quant.	25							
1	40							
(WL_2)	60							
	80							
Partial	15							
Quant.	25							
2	40							
(WL_1)	60							
	80							
Partial	15							
Quant.	25							
3	40							
(WL_0)	60							
	80							
Partial	15							
Quant.	25							
4	40	1.84	6.96	.576	2.18	.0495	.1593	no
(WL_3)	60	2.09	7.91	.620	2.34	.0313	.0449	yes
	80	2.37	8.97	.704	2.66	.0176	.0265	yes
Full	15	3.03	11.47	.972	3.68	.0014		
Quant.	25	3.21	12.15	.972	3.68	.0041		
	40	3.39	12.83	.972	3.68	.0021		
	60	3.77	14.27	.972	3.68	.0006		
	80	4.06	15.37	.972	3.68	.0002		

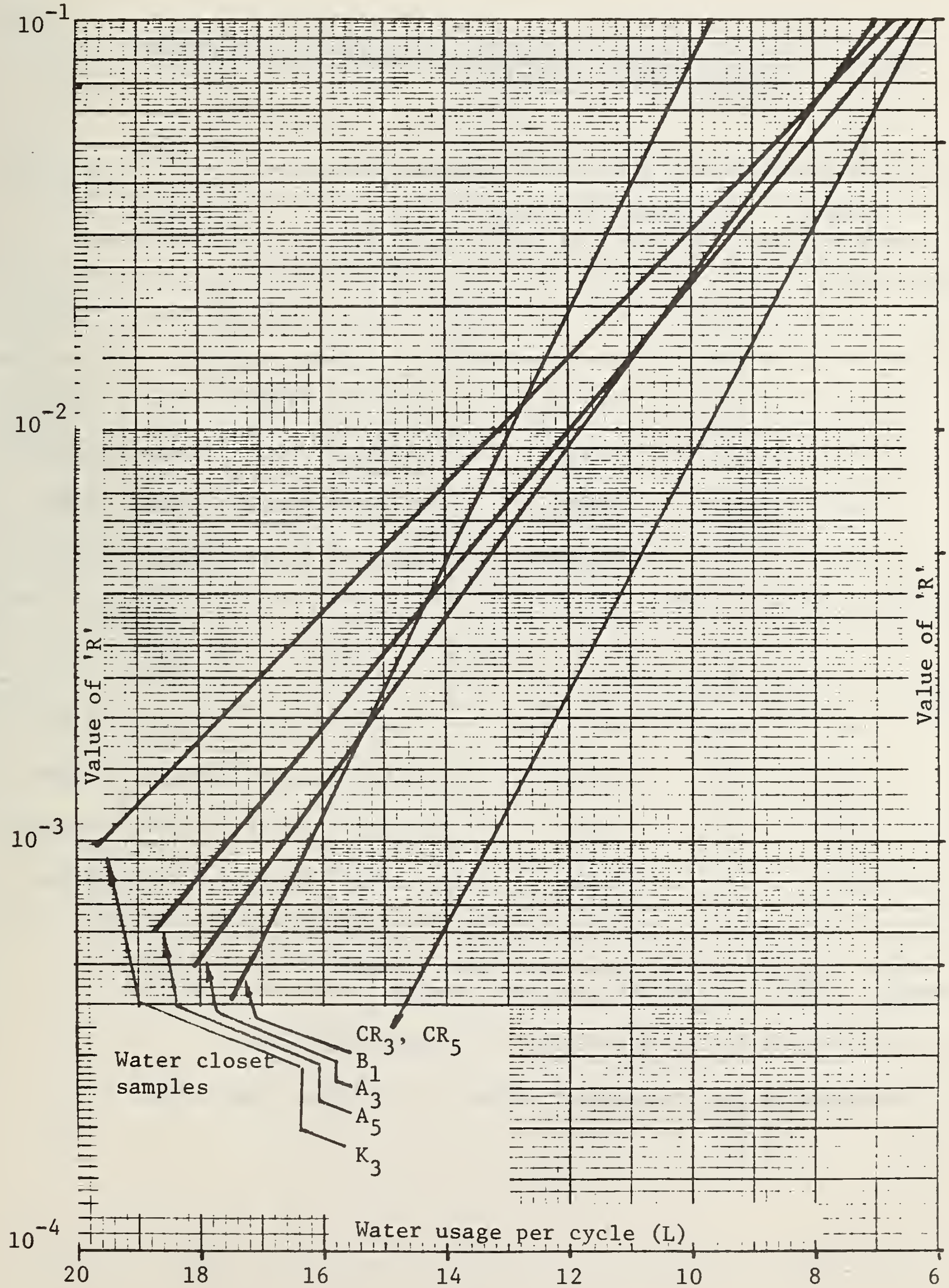

Figure 6. Relative concentration ratio 'R' as a function of the water usage per flush cycle for the water closet samples tested

Table 7. Water Exchange-Relative Concentration Values for European Water Closets

Group	Sample Identification	Volume in liters of water in well	Flush volume in liters			
			9.0	7.5	6.0	4.5
A	A	1.75	0.007	0.009	0.023	0.135
	D	1.91	0.010	0.015	0.026	0.074
	F	1.82	0.013	0.023	0.042	0.052
	H	2.42	0.031	0.043	0.066	0.123
			8.0	7.0	6.0	4.0
B	I_4	1.19	0.001	0.001	0.001	0.005
	Y_8	2.16	0.002	0.002	0.012	0.036
	N_9	1.87	0.001	0.001	0.006	0.028
	H_5	2.18	0.003	0.013	0.032	0.089

Note: Samples I_4, Y_8, N_4, H_5 designate water closets manufactured by: Italy, Israel, The Netherlands and Hungary

Group A: Prepared by Brunel University - England (Ref. 14)

Group B: Prepared by the Standards Institution of Israel (Ref. 15)

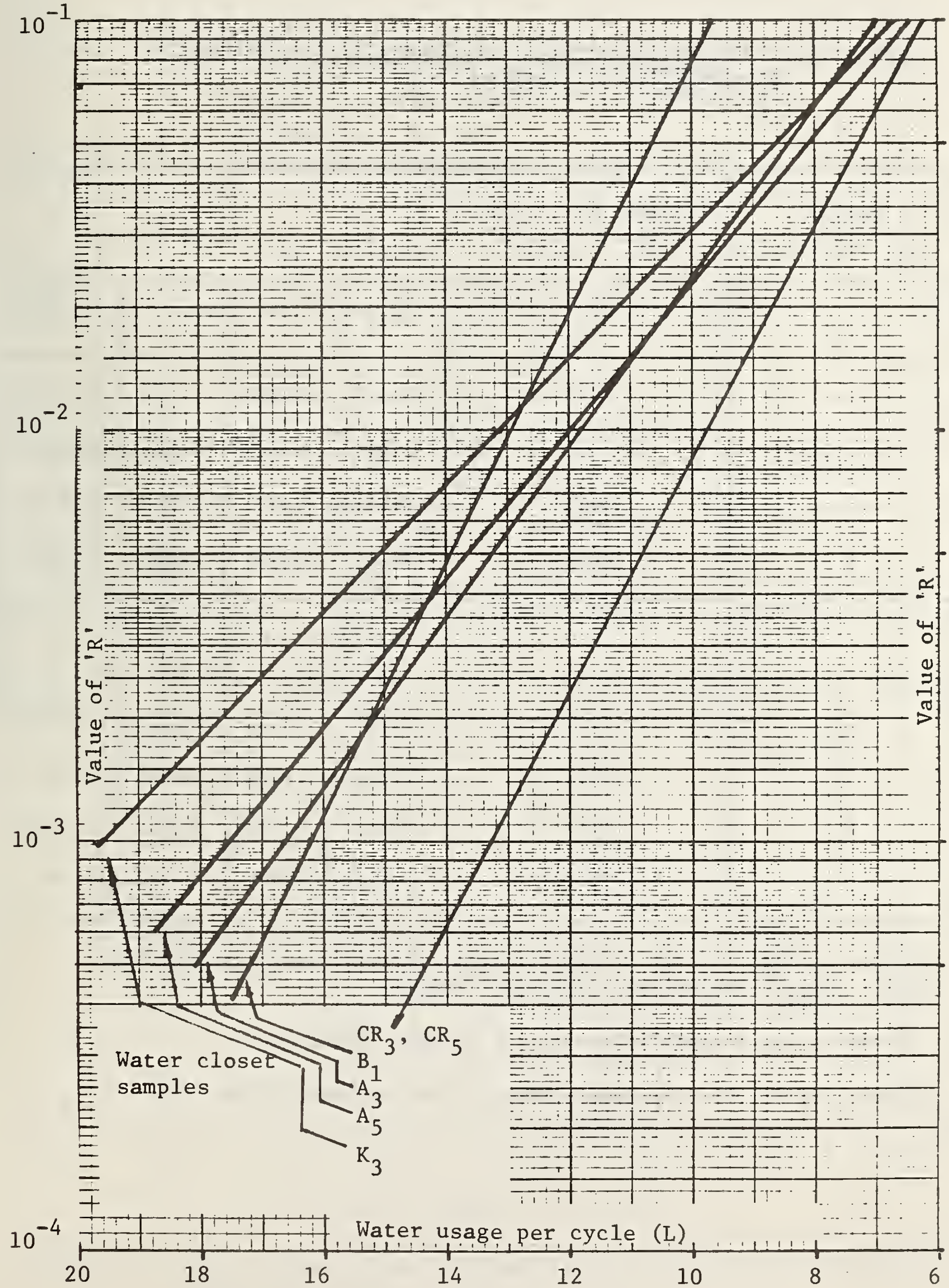

Figure 6. Relative concentration ratio 'R' as a function of the water usage per flush cycle for the water closet samples tested

Table 7. Water Exchange-Relative Concentration Values for European Water Closets

Group	Sample Identification	Volume in liters of water in well	Flush volume in liters			
			9.0	7.5	6.0	4.5
A	A	1.75	0.007	0.009	0.023	0.135
	D	1.91	0.010	0.015	0.026	0.074
	F	1.82	0.013	0.023	0.042	0.052
	H	2.42	0.031	0.043	0.066	0.123
			8.0	7.0	6.0	4.0
B	I_4	1.19	0.001	0.001	0.001	0.005
	Y_8	2.16	0.002	0.002	0.012	0.036
	N_9	1.87	0.001	0.001	0.006	0.028
	H_5	2.18	0.003	0.013	0.032	0.089

Note: Samples I_4, Y_8, N_4, H_5 designate water closets manufactured by: Italy, Israel, The Netherlands and Hungary

Group A: Prepared by Brunel University - England (Ref. 14)

Group B: Prepared by the Standards Institution of Israel (Ref. 15)

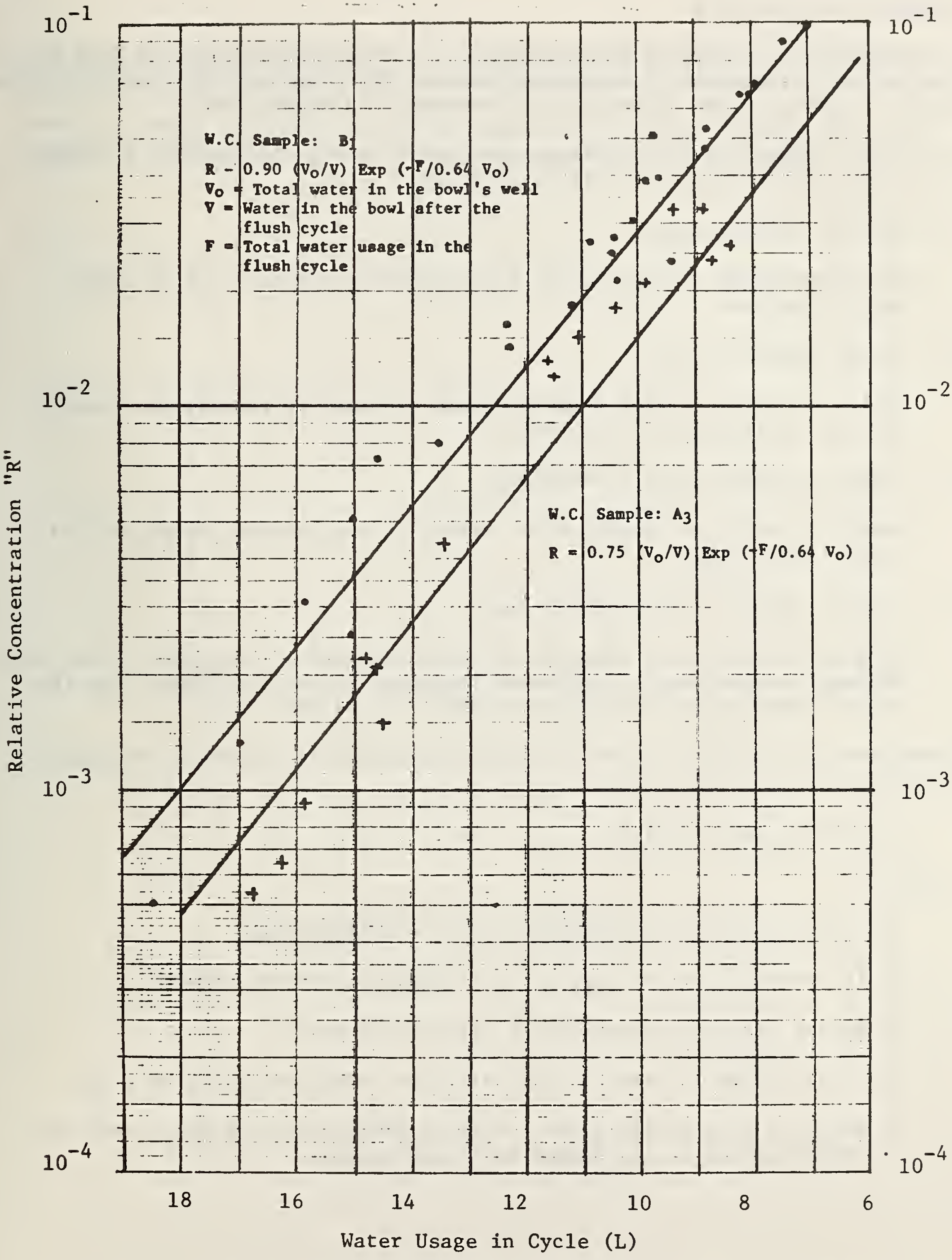

Figure 7. Water exchange test - comparison of laboratory data and fitted derived equation

Mathematical Modeling

A mathematical expression for describing the water exchange in the bowl was derived on the basis of some assumptions and evaluated with the laboratory test data. Details of the derivation are described in Appendix B.

The water exchange may take place with the following processes at different time intervals during the total flush cycle:

a. Apparent piston action

The fresh water flowing to the bowl displaces the water in the bowl which flows out.

b. Instantaneous mixing

Each fresh water quantity which enters the bowl is immediately mixed with the total water in the well.

c. Complete mixing prior to discharge

Discharge takes place only after mixing of the incoming water and the water in the well.

d. Complete mixing with no discharge

This process actually takes place toward the end of the flush cycle. As siphonic action ceases, the water remaining in the trap mixes with the refill fresh water which fills the well to its weir level.

These assumptions lead to the following expression for the water exchange process:

$$R_1 = K_1 \, (W_o/w) \, e^{-V_o/K_2 W_o}$$

where:

R_1 is the relative concentration ratio (dimensionless)

V_o is the total water usage in the flush cycle (volume units)

W_o is the volume of water in the well to the weir

W is the volume of water in the well after the flush cycle ($W \leq W_o$)

K_1 and K_2 are constants which are evaluated by the laboratory test data, with the use of the method of "least squares."

In tables 8a and 8b and figure 7, a comparison between the values obtained with this equation and the laboratory test data are indicated. This expression leads to a reasonably good agreement with the laboratory data for cases for which siphonic action took place in the bowl. In the absence of siphonic action in the flush cycle, this expression is not valid.

Table 8a. Concentration ratios before and after flushing - comparison between laboratory data and results obtained by empirical equation

Sample B_1

Water Exchange Test

R_1			R_2		
	Empirical Equation			Empirical Equation	
Lab. Data	1st Method	2nd Method	Lab. Data	1st Method	2nd Method
0.102	0.100	0.099	0.497	0.223	0.049
0.090	0.094	0.094	0.438	0.180	0.031
0.070	0.078	0.077	0.377	0.152	0.022
0.047	0.054	0.054	0.284	0.131	0.016
0.038	0.042	0.041	0.056	0.079	0.0056
0.065	0.061	0.061	0.422	0.219	0.047
0.065	0.059	0.058	0.384	0.196	0.037
0.052	0.048	0.048	0.298	0.168	0.028
0.039	0.035	0.035	0.064	0.150	0.021
0.026	0.021	0.021	0.035	0.134	0.017
0.024	0.033	0.032	0.071	0.204	0.040
0.033	0.031	0.031	0.049	0.168	0.027
0.027	0.026	0.025	0.038	0.137	0.018
0.021	0.017	0.016	0.031	0.145	0.020
0.016	0.011	0.010	0.016	0.134	0.017
0.030	0.022	0.022	0.049	0.219	0.049
0.025	0.021	0.021	0.031	0.178	0.031
0.018	0.016	0.016	0.025	0.261	0.025
0.014	0.010	0.010	0.018	0.148	0.020
0.0078	0.0059	0.0059	0.010	0.141	0.019
0.0072	0.0035	0.0034			
0.0051	0.0030	0.0029			
0.0030	0.0021	0.0021			
0.0013	0.0014	0.0014			
0.0005	0.0008	0.0008			
C1	0.90	0.90	C1	0.93	0.93
C2	0.54	0.53	C2	1.69	0.83

Equations:

$R_1 = (Cq_1 - C_b)/(Ci_1 - C_b)$

$R_2 = (Cq_1 - C_b)/(Ci_2 - Cb)$

C_b = Background concentration of sodium bromide

Ci_1 = Initial conc.- first flush

Cq_1 = final conc. after flush

Ci_2 = Initial conc.- second flush

Cq_2 = Final conc. after flush

$R = C_1 \ (Vo/V) \exp(-F/C_2 \ V)$

Vo = Volume of water in W.C. up to weir

V = Volume of water cn W.C. before flushing

F = Total flow in flush cycle

C_1, C_2 = Coefficients to be evaluated

Subject to:

By 1st method:

$$\sum_{i=1}^{n} (R_{lab} - R)_i^2 = E = \min$$

By 2nd method:

$$\sum_{i=1}^{n} (R_{lab} - R)_i^2 / R_{lab}^2 = E = \min$$

Table 8b. Concentration ratios before and after flushing - comparison between laboratory data and results obtained by empirical equation

Water Exchange Test

Sample A_3

	R_1			R_2	
	Empirical Equation			Empirical Equation	
Lab. Data	1st Method	2nd Method	Lab. Data	1st Method	2nd Method
-	-	-	-	-	-
0.026	0.039	0.030	0.197	0.061	
0.033	0.029	0.021	0.167	0.068	
0.021	0.020	0.014	0.023	0.051	
0.015	0.012	0.0083	0.016	0.051	
0.033	0.026	0.018	0.073	0.052	
0.024	0.023	0.016	0.121	0.046	
0.018	0.015	0.011	0.012	0.058	
0.013	0.010	0.007	0.010	0.045	
0.008	0.006	0.004	0.010	0.037	
0.017	0.010	0.007	0.014	0.047	
0.012	0.010	0.007	0.013	0.046	
0.011	0.008	0.005	0.010	0.039	
0.006	0.005	0.003	0.007	0.028	
0.003	0.003	0.002	0.003	0.021	
0.006	0.009	0.006	0.008	0.043	
0.004	0.007	0.004	0.007	0.037	
0.004	0.005	0.003	0.003	0.029	
0.002	0.003	0.002	0.002	0.022	
0.001	0.002	0.001	0.001	0.016	
0.0005	0.001	0.0008			
0.002	0.004	0.002			
0.002	0.003	0.002			
0.002	0.002	0.0014			
0.0006	0.0017	0.0010			
C1	0.75	0.75	C1	0.80	
C1	0.64	0.58	C2	0.96	

Equations:

$$R_1 = (Cq_1 - C_b)/(Ci_1 - C_b)$$

$$R_2 = (Cq_1 - C_b)/(Ci_2 - Cb)$$

C_b = Background concentration of sodium bromide

Ci_1 = Initial conc.- first flush

Cq_1 = final conc. after flush

Ci_2 = Initial conc.- second flush

Cq_2 = Final conc. after flush

$$R = C_1 \,(Vo/V)\, \exp\,(-F/C_2\, V_o)$$

Vo = Volume of water in W.C. up to weir

V = Volume of water on W.C. before flushing

F = Total flow in flush cycle

C_1, C_2 = Coefficients to be evaluated

Subject to:

By 1st method:

$$\sum_{i=1}^{n} (R_{lab} - R)_i^2 = E = \min$$

By 2nd method:

$$\sum_{i=1}^{n} (R_{lab} - R)_i^2 / R_{lab}^2 = E = \min$$

4.4 Test of Paper Removal

Table 9 indicates the results of the Paper Removal Test as carried out according to the test procedure described in Section 3.4. Similar results were obtained with all the water closet samples, from which, the following conclusions were drawn:

- As long as siphonic action takes place in the bowl, all the paper load is removed from the water closet.

- In the absence of an adequate siphonic action, the toilet paper is not evacuated from the bowl.

The requirement that the water closet must be capable of removing the toilet paper load at all times is reasonable, although it may stem from aesthetic reasons only. The above conclusions indicate that there is no need for a performance test of paper removal since an adequate siphonic action will remove the paper wastes, and with the absence of an adequate siphonic action, the paper wastes will not be flushed out.

4.5 The Rim Wash Test

The methods considered for testing the adequacy of the rim wash were described in Section 3.4. The problems experienced with these methods were in the area of elimination of subjective judgment, repeatability of results, simplicity of preparation of the test medium, and problems in quantification and rating of the results.

Table 10 summarizes the results of a rim wash test as obtained by the "dots test," "line marking test" and the "saw-dust test." No attempt was made to statistically evaluate the repeatability of the results. The saw dust test was considered unsatisfactory because the outcome of the tests yielded results which required undue subjective judgement since particles of saw-dust remain on the bowl surfaces and the observer finds it difficult to evaluate the results even on a basis of a pass/fail criterion unless the requirement calls for a complete removal of all particles from the bowl surfaces. The results of the dots test and lines test are reasonably satisfactory since the outcome of both tests can be quantified. The repeatability of the results has not been satisfactory. This can be improved by using a better test medium for yielding more consistent results.[1]

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[1] These tests were performed by marking the dots and lines with a water soluble paint with an 1/8" brush. A better medium (used towards the end of the laboratory work) was a thin water soluble felt-tip pen which yielded more uniform marks. This medium was used in the subsequent experiments for the single line test and enable a higher mode of uniformity in drawing the line, with some improvement in test reproducibility.

Table 9. Test of Paper Removal

Result of Test Runs

Test Load: Six double strips cut from a toilet paper roll. Each strip measured 4 1/2 x 4 1/2".

The paper is placed in the bowl, and the toilet flushed. This procedure was repeated for a load of 12 double strips. Except for two flush cycles, identical results were obtained.

Water per Flush Cycle ℓ	First Run			Second Run		
	1st flush cycle	2nd flush cycle	Siphonic Action	1st flush cycle	2nd flush cycle	Siphonic Action
6.8	0	6	no	0	6	no
7.0	0	6	no	0	6	no
7.7	0	6	no	0	6	no
7.9	0	0	no	0	0	no
8.3	0	6	no	0	6	no
8.5	0	6	no	0	6	no
8.9	0	6	no	0	6	no
9.3	0	0	yes	0	6	no
9.4	0	4	no	0	4	no
9.5	0	0	yes	0	0	yes
9.8	0	0	yes	0	0	yes
10.2	0	0	yes	0	0	yes
10.8	0	1	yes	0	0	yes
11.5	0	0	yes	0	0	yes
11.9	0	0	yes	0	0	yes

Table 10. Rim Wash Test

Experiments with three methods:

Dots marking test   1/8" dots spaced 1/2" apart were marked in the bowl with water soluble paint. The numbers in the table represent the number of unwashed dots after the flush cycle.

Line marking test   1/8" lines were marked on the circumference of the bowl spaced 3/4" apart vertically with the paint medium as for the dots test. The numbers in the table represent the total number of 1/4" marks not washed in the flush.

Saw-dust test   The bowls surface was wetted and fine saw dust was sprayed by hand in the bowl up to a level of 3/4" from the rim. The numbers in the table represent the total number of 1/2 x 1/2" squares not flushed in the flush cycle.

Line Pressure		Water Usage	Dots Marking Test					Line Marking Test					Saw Dust Test				
Partial Flush Quantity																	
			Runs					Runs					Runs				
kPa	Psi	ℓ	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean
103	15	7.0	4	3	4	5	4	9	7	14	10	10	1	0	1	0	0.5
276	40	7.9	3	2	4	3	3	6	9	5	5	6	1	0	0	0	0
552	80	9.8	3	3	2	1	2	6	4	6	5	5	1	1	0	0	0.5
Total Flush Quantity																	
103	15	14.6	3	3	4	3	3.5	4	5	4	6	5	0	0	0	0	0
276	40	15.9	2	1	1	3	2	4	2	5	5	4	0	0	0	0	0
552	80	18.3	2	5	0	3	2	4	4	6	5	4	0	0	0	0	0

The preparation of both lines and dots tests turned out to be a rather laborious task. It was therefore decided to test the water closet samples by the method adopted by the revised ANSI A112.19.2 Standards, called the "Ink Test" as described in Section 3.4.

Table 11 describes the results obtained with tests of three water closets. An adequate rim wash, depends primarily upon the proper distribution of the rim holes, and only to a small extent on the quantity of water used per flush cycle. This is seen in the small change in the rim wash effectiveness with increased water in the flush cycle. This conclusion may not apply to all water closets, and therefore this line mark test is necessary for testing two-step flush devices for the adequacy of the rim wash also for partial flush cycles.

Table 11. Rim Wash Test - The Ink Test

Test Results of Three W.C. Samples Tested.

Test procedure as described in the revised ANSI A112.19.2 Standard:

Test medium: A fine tipped felt pen containing a dark colored water soluble ink.

A line is drawn around the circumference of the bowl one inch below the rim. The bowl is flushed and the total length of the remaining unwashed line segments is measured in inches. Measure to the nearest 1/8 inch.

W.C.	Flush Cycle	Flush Per Cycle ℓ	Total Length of Unwashed Line Segments (in)				
			Run 1	Run 2	Run 3	Run 4	Mean
CR_3	Full Flush	11.5	1/2	1/2	1	1/4	1/2
		12.8	1/4	0	1	1	1/2
		13.8	1/2	1	3/4	1/2	3/4
	Partial Flush	8.9	1 1/4	2	1 1/2	1 1/2	1 5/8
		9.4	1/2	1 1/2	1	2	1 1/4
		10.9	1/2	1 1/2	3/4	3/4	1
A_2	Full Flush	11.5	1/2	1/2	1/4	0	1/4
		12.9	1/4	1/8	1/8	1/8	1/8
		15.4	0	0	0	0	0
	Partial Flush	6.9	3/4	3/4	1/4	3/4	1/2
		9.1	1/4	1/4	1/4	1/4	1/4
K_3	Full Flush	13.0	0	0	0	0	0
		14.5	0	0	0	0	0
		16.0	0	0	0	0	0
	Partial Flush	11.1	1/4	0	1/2	1/8	1/4
		11.8	0	0	0	1/8	0
		12.5	0	0	0	0	0

4.6 Tests of the Two-Step Flush Devices

The purpose of testing the manufactured two-step flush mechanism devices was to study the mode of operation and observing typical problems which may effect their performance. The tests were not intended for making a comparison among the existing available systems in the market.

Appendix B describes the mechanisms which were available at the time of the laboratory testing.

Test Results

Sample M_1

This device is designed to replace only the flapper valve in the existing flushing mechanism in the toilet. Installing this device in the water closets revealed the following:

- Leakage through the valve. The flapper valve would not rest properly on the tank outlet base and water leaks to the bowl.

- Inconsistencies in delivering fixed water quantities. The following table shows partial flush quantities as obtained in a partial flush cycle for one water closet sample. The following table indicates a typical distribution of flows to water closet under testing.

	Sample B_1 - Partial Flush Cycle				
Cycle No.	1	2	3	4	5
Gallons	3.40	3.02	3.34	2.90	2.77
Liters	12.8	11.4	12.6	11.0	10.5

In addition to these inconsistencies, the volumes of flush water are relatively large. There are three adjustments in this device. Prior to testing, the device was set to deliver the minimum flush quantities. This device was disqualified for further testing.

Sample M_2

This device is designed to replace the whole flushing mechanism in the tank, except for the existing overflow arrangement, and is composed of intricate components and parts to obtain the desired full and partial flush cycles.

The following features were observed:

- Complexity of installation. Difficulties were encountered in aligning all parts of the mechanisms

- Leakage through the flush valve. All the toilet samples tested with this device experienced leakage through the valve to varying degrees. This device was disqualified for further testing.

Sample M_3

This device is designed to completely replace all the parts of the existing mechanism. This in itself is an advantage since this device is not dependent on existing parts in the tank and is installed as a complete flush valve unit. The undesired feature of the device is that the tank must be disassembled prior to installation. This device could not be tested in two water closets. In the first one, the mechanism of the device interferred with the float of the ball cock. In the second one, its total height exceeded the height of the water closet tank.

Samples M_4 and M_5 were obtained upon termination of the laboratory test, and are only described in Appendix A.

Tables 11a through 11d describe the test results of mechanism M_3 as performed with four W.C. samples, where the following findings may be summarized:

- Siphonic action is not obtained for partial flush quantities up to 10 liters.

- Paper removal is not attained in the absence of a fully developed siphonic action.

- Poor water exchange occurs in the absence of siphonic action.

Results of the laboratory tests indicate the following problems with the selected samples: Incompatibility of the devices with existing water closets which results in impossibility of installation, leakage through the flush valve, and inconsistency in delivering constant quantities of water per full and partial flush cycles.

Table 11a. Summary of the Tests Carried Out With a Two-Step Flush Device

W.C. Sample: B_1 Mechanism Sample: M_3

I. Full Flush Quantity

P_t	W		Siphonic Action				Pellets Remain	hr		Water Exchange
psi	gal	lit.	1st	2nd	3rd	4th		inch	mm	R_1
15	3.11	11.8	yes	yes	yes	yes	10	0	0	0.012
25	3.28	12.4	yes	yes	yes	yes	8	0	0	0.0088
40	3.51	13.3	yes	yes	yes	yes	6	0	0	0.0084
60	3.77	14.3	yes	yes	yes	yes	0	0	0	0.0038
80	3.99	15.1	yes	yes	yes	yes	0	0	0	0.0027

II. Partial Quantity of Flush

P_t	W		Siphonic Action		Pellets Remain	hr		Rim Wash Test			Water Exchange		Paper Removal	
psi	gal	lit.	1st	2nd		inch	mm	Run 1	Run 2	Mean	R_1	R_2	Run 1	Run 2
15	1.86	7.0	yes	no	All	0.9	23	2	1	2 1/2	0.061	0.437	12	12
25	2.00	7.6	yes	no	All	0.9	22	-	-	-	0.060	0.382	12	12
40	2.15	8.1	yes	no	90%	0.8	21	1 1/2	1	2	0.047	0.268	12	12
60	2.35	8.9	yes	yes	150	0.8	21	-	-	-	0.045	0.056	0	0
80	2.55	9.7	yes	yes	100	0.8	20	1 3/4	1 1/2	1 1/2	0.022	0.038	0	0

- The nomeclature is the same as for Table 3.
- Pellets test was performed for the 1st and 2nd flush cycles.

Table 11b. Summary of the Tests Carried Out With a Two-Step Flush Device

Sample: A_5 Mechanism Sample: M_3

I. Full Flush Quantity

P_t	W		Siphonic Action				Pellets Remain		hr		Water Exchange
			1st	2nd	3rd	4th	1st	2nd			R_1
psi	gal	lit.							inch	mm	
15	3.75	14.21	yes	yes	yes	yes	10	12	0	0	0.0015
25	4.04	15.31	yes	yes	yes	yes	1	3	0	0	0.00070
40	4.30	16.30	yes	yes	yes	yes	0	0	0	0	0.00030
60	4.69	17.78	yes	yes	yes	yes	0	0	0	0	0.00005
80	5.17	19.59	yes	yes	yes	yes	0	0	0	0	not detected

II. Partial Quantity of Flush

P_t	W		Siphonic Action				Pellets Remain		hr		Rim Wash Test			Water Exchange		Paper Removal	
			1st	2nd	3rd	4th	1st	2nd			Run 1	Run 2	Mean	R_1	R_2	Run 1	Run 2
psi	gal	lit.							inch	mm							
15	2.36	8.94	no	no	no	no	23		0.5	9	1 1/2	1 1/2	1 1/2	0.026	0.108	6	6
25	2.48	9.40	yes	yes	no		20	120	0.4	8				0.018	0.033	0	0
40	2.70	10.23	yes	yes	no		6	40	0.3	7	1	1	1	0.014	0.020	0	0
60	3.05	11.56	yes	yes	yes	yes	3	25	0.3	6				0.012	0.013	0	0
80	3.28	12.43	yes	yes	yes	yes	0	15	0	0	1/2	1	3/4	0.0027	0.0037	0	0

- The nomeclature is the same as for Table 3.
- Pellets test was performed for the 1st and 2nd flush cycles.

Table 11c. Summary of the Tests Carried Out With a Two-Step Flush Device

W.C. Sample: CR_5

I. Full Flush Quantity

Mechanism Sample: M_3

P_t	W		Siphonic Action				Pellets Remain	hr		Rim Wash Test			Water Exchange	Paper Removal	
			1st	2nd	3rd	4th				Run 1	Run 2	Mean	R_1	Run 1	Run 2
psi	gal	lit.						inch	mm						
15	3.11	11.7	yes	yes	yes	yes	24	0	0	0	0	0	.0221	0	0
25	3.59	13.59	yes	yes	yes	yes	15	0	0	0	0	0	.0103	0	0
40	4.18	15.82	yes	yes	yes	yes	2	0	0	0	0	0	.0036	0	0
60	4.55	17.22	yes	yes	yes	yes	0	0	0	0	0	0	.0010	0	0
80	9.88	18.47	yes	yes	yes	yes	0	0	0	0	0	0	.0003	0	0

II. Partial Quantity of Flush

P_t	W		Siphonic Action				Pellets Remain	hr		Rim Wash Test			Water Exchange		Paper Removal	
			1st	2nd	3rd	4th				Run 1	Run 2	Mean	R_1	R_2	Run 1	Run 2
psi	gal	lit.						inch	mm							
15	1.53	5.79	no	*	*	*	*	*	*	*	*	*	*	*	*	*
25	2.03	7.68	*	*	*	*	*	*	*	*	*	*	*	*	*	*
40	2.76	10.45	yes	yes	no		69	0.5	13	3"	1"	2"	.0350	.110	0	0
60	3.75	14.19	yes	yes	yes	yes	38	0.4	6	1/2"	2"	1.25"	.0231	.0304	0	0
80	4.33	16.39	yes	yes	yes	yes	20	0	0	0	0	0	.0233	.0221	0	0

* No siphonic action on 1st flush.
\- Pellets test was performed in the first flush cycle.

Table 11d. Summary of the Tests Carried Out With a Two-Step Flush Device

W.C. Sample: A_3

I. Full Flush Quantity

P_t	W		Siphonic Action				Pellets Remain*		hr		Water Exchange
			1st	2nd	3rd	4th	1st	2nd			R_1
psi	gal	lit.							inch	mm	
15	3.20	12.12	yes	yes	yes	yes	5	5	-	-	0.012
25	3.40	12.88	yes	yes	yes	yes	5	6	-	-	0.0083
40	3.65	13.83	yes	yes	yes	yes	4	3	-	-	0.0084
60	4.02	15.24	yes	yes	yes	yes	1	1	-	-	0.0039
80	4.36	16.52	yes	yes	yes	yes	1	2	-	-	0.0027

II. Partial Quantity of Flush

P_t	W		Siphonic Action				Pellets Remain*		hr		Rim Wash Test			Water Exchange		Paper Removal	
			1st	2nd	3rd	4th	1st	2nd			Run 1	Run 2	Mean	R_1	R_2	Run 1	Run 2
psi	gal	lit.							inch	mm							
15	1.72	6.52	no				-	-	1.0	26	1 1/2	1 1/2	1 1/2	-	-	-	-
25	1.83	6.93	yes	no			500	100%	1.0	25				0.059	0.255	6	6
40	2.10	7.96	yes	no			76	100%	0.7	18	1	1	1	0.048	0.215	6	6
60	2.31	8.75	yes	no			50	90%	0.4	10				0.045	0.044	6	6
80	2.63	9.98	yes	yes	yes	yes	14	80	0.5	11	1/2	0	1/4	0.022	0.024	0	0

* Pellets test was performed for the first and second flush cycles.

5. RECOMMENDED CRITERIA AND TESTING PROCEDURES FOR TWO-STEP FLUSH DEVICES FOR SIPHONIC WATER CLOSETS

The following test procedures are prepared as recommendations for voluntary consensus standards and are based on tests conducted at the National Bureau of Standards' Plumbing Research Laboratory. These tests were performed with siphonic water closet bowls presently marketed by the major U.S. manufacturers. The water closet samples included 5 gallon and water conserving (3 1/2 gallon) systems of the "close-coupled" type. These samples were tested in combination with two-step flush devices which were separately acquired and installed in the water closets for the evaluation of their capabilities and limitations.

The following criteria and testing procedures of two-step flush devices may be incorporated in one or more standards for sanitary fixtures. These recommendations were prepared with the initial intent to supplement the revised ANSI A112.19.2 Standard and, as such, reference is made to the nomenclature and the test procedure in that document.

5.1 Categories of Two-Step Flush Devices

At present, two step flush devices are marketed as distinct systems for the replacement of the existing hardware in the toilet tanks. As such, they are designed for a specific type and model of a water closet available in the market. Therefore, their design may be categorized as follows:

a. Designed to provide means for geometrical lateral and vertical adjustment to facilitate installation and operation for any water closet.

b. Designed to provide means for adjusting the full and partial water quantities flushed per cycle.

c. No means for adjustment for installation, operation, or total flows per flush cycle.

If the device does not meet categories a and b, the device should be tested with the water closet for which it was designed. If the device meets categories a and b, it should be tested with three water closet bowls. The device will undergo all the tests described in Article 5.4 when connected to one out of the three selected water closet samples. For the other two water closet samples, only the tests prescribed in Articles 5.2.4 and 5.2.5 will be carried out.

The water closet to which the device is installed shall comply with all the requirements as stated in the appropriate standard such as ANSI A.112.19 when this water closet is tested with its original flushing mechanism for the full flush cycle.

5.2 Criterion For Two-Step Flush Devices

5.2.1 General

The device shall be designed and constructed for delivering two distinct quantities of water to the water closet bowl.

The device shall be provided with means for a simple selection of the mode of operation for the choice of the appropriate flush cycle.

The device, as installed, shall not interfere with the function of any remaining pre-existing mechanisms in the water closet tanks, such as the water flow from the water supply, ball cock operation, and water level control.

5.2.2 Mechanical Performance of Two-Step Flush Devices

The mechanism and all its parts shall be of sound construction and composed of materials capable of withstanding the forces acting on the system in a normal operating mode of full and partial flush cycles.

5.2.3 Watertightness of the Flush Valve

No leakage shall occur through the flush valve during the filling of the tank and after termination of the flush cycle when the water in the tank has reached the "Water Line."

5.2.4 Consistency in Delivering Full and Partial Flush Quantities

The nominal full and partial flush quantities of water shall be consistently delivered for consecutive flush cycles with deviation that will not exceed 500 ml (0.13 gallons).

5.2.5 Hydraulic Performance - Siphonic Action

This test shall be carried out for conventional siphonic water closet bowls.

5.2.5.1 Full Flush Cycle

A siphonic action shall follow a full flush cycle at all times.

5.2.5.2 Partial Flush Cycle

A siphonic action shall follow a partial flush cycle for at least four consecutive flush cycles.

5.2.6 Trap Seal Retention

Upon termination of the partial or full flush cycle, the trap seal depth in the bowl shall not be reduced by more than 25 mm (one inch).

5.2.7 Removal of Liquid Wastes - Water Exchange

5.2.7.1 For each full flush, a dilution ratio of at least 100 shall be obtained.

5.2.7.2 For each partial flush, a dilution ratio of at least 25 shall be obtained.

5.2.8 Paper Removal for Partial Flush Cycles

The paper load appropriate for application when urine removal only is required shall be removed from the water closet bowl upon termination of the partial flush cycle.[1]

5.2.9 Rim Wash

The mode of flushing attained by the two-step flush device shall not be degraded as basically provided by the design of the rim jets in the water closet to reach all the exposed surfaces in the bowl. In the method of testing as prescribed in Section 5.3, the total length of ink line segments remaining on the flushing surface shall not exceed 50 mm (2 in) and no individual segment shall be longer than 12 mm (1/2 in), for the full and partial flush cycles.

5.3 <u>Test Equipment and Apparatus Set Up</u>

The equipment and apparatus for the water closet tests are as specified in the revised ANSI A112.19.2 Standard. Additional optional instruments for the water exchange test are specified in Section 5.4.3.[2]

Mount the device into the tank of the water closet tested following the manufacturers instructions. If the devices contain several discrete possible adjustments for attaining partial flush quantities, test and report the results for all the set ups. If the device can be adjusted for delivering a continuous range of partial flush quantities, select and test for three discrete quantities.

If the ball cock can be adjusted, it is recommended to adjust the ball cock such that it closes at the marked "Water Line" in the tank for a static pressure of the water supply of 40 psi (276 kPa).

---

[1] No test is required for the removal of paper wastes. It has been established in the laboratory tests at the National Bureau of Standards Laboratory that an adequate siphonic action in the bowl will evacuate the paper load.

[2] A "life test" assembly and apparatus is required for the test specified in 5.4.6.

5.4 Testing Procedures

Testing procedures will be carried out in the following sequence:

5.4.1 Watertightness of Flush Valve

Empty the tank of all its water content, fill the bowl to its weir level, and disconnect the refill tube from the overflow pipe. Set the water supply static pressure nominally to 40 psi[1] (276 kPa) and place a one-liter vessel under the bowl. Remove the vessel after the water in the tank has reached the water level and replace by an empty dry vessel, for 20 minutes. The water volume in the first vessel shall not exceed 100 ml (0.3 gallons), and no water shall be observed in the second vessel.

5.4.2 Consistency in Delivering Full and Partial Flush Quantities

This test is performed for water supply static pressure conditions of 20 psi (138 kPa), and 80 psi (552 kPa), ten times for each pressure. Adjust the water supply pressure, allow sufficient time for the tank to be filled, and trip the flushing device. Record the water quantity passed during the flush cycle, in a manner similar to the suggested Table 12. The "standard deviation" as defined in Table 12 and calculated for ten flush cycles shall not exceed 500 ml (0.13 gallons).

5.4.3 Siphonic Action and Trap Seal Retention

The following tests will be carried out for each water supply static pressure of 20, 40, 60, and 80 psi (138, 276, 404, and 552 kPa):

5.4.3.1 Test for the Partial Flush Cycle

Make sure that the bowl is full to the weir. Open the water supply valve to fill the water closet tank to the marked "water line". Observe and record the flushing mode for attaining siphonic action.

Note: An adequate siphonic action is defined as that mode of flow which causes the water level in the bowl to drop at least to the dip of the trap.

After flushing, measure the depletion of the trap seal height with reference to the level of the weir.

With the water in the bowl left from the previous flush cycle, repeat four more times to make up five partial flush cycles.

Test Criteria:

a. Siphonic action shall take place for at least the first four consecutive partial flush cycles.

b. Maximum trap seal depletion shall not exceed 25 mm (1 in).

---

[1] This pressure is adopted as reference value only.

5.4.3.2 Test for the Full Flush Cycle

From the results of the tests for the partial flush cycle, determine the maximum depletion of the trap seal.

If the value of the maximum trap seal depletion for partial flush is less than 5 mm (0.2 inches)[1], there is no need for further testing. If the value is larger than 5 mm[1], perform the following tests:

5.4.3.2.1 Fill the bowl to the weir. Remove water from the bowl to attain a trap seal height commensurate with the maximum trap seal depletion as obtained in 5.4.3.1. Trip the flushing device to obtain a full flush cycle. Observe for siphonic action. Repeat this test four more times.

Test Criteria: Siphonic action shall be attained for all the five flush cycles.

Record the findings of the tests in 5.4.3 in a form similar to the one as suggested in Table 13.

5.4.3.2 If the maximum trap seal depletion exceeded 5 mm[(2)], it is required to repeat all the performance tests specified in an appropriate water closet standard, e.g., ANSI A112.19.2, to ascertain that the performance of the bowl was not affected by the introduction of the device.

5.4.4 Water Exchange Test

The water exchange as determined by the dilution ratio is evaluated for two consecutive flush cycles, both for the full and partial flush cycles. In the first cycle, the water in the bowl is to its weir level and the test medium is added to the well of the bowl. In the second cycle, the water in the bowl remains as left from the first cycle and a new test medium is added for the second flush cycle.

5.4.4.1 <u>The Dye Test</u>

The test is performed as prescribed in the revised ANSI A112.19.2, Article 5.4.5, where the criteria is as follows:

- A dilution ratio of at least 100 shall be obtained for the full flush cycle.
- A dilution ratio of at least 25 shall be obtained for the partial flush cycle.

---

1 A depletion in the trap seal up to 5 mm is unlikely to affect the performance of the bowl in comparison to its performance with the original mechanisms.

2 A trap seal reduction of more than 5 mm may affect the performance of the water closet in comparison to its performance with its original mechanisms.

5.4.4.2 Water Exchange With Sodium Bromide as Test Medium[1]

This procedure is proposed as an alternative to the dye test and may have its merits in the following aspects:

- More accurate results as compared to the dye test
- Relatively easy preparation of the test medium
- Materials and instruments:
  - pH conductivity meter
  - Electrodes for measuring concentrations of bromide ions in a sodium bromide solution
  - Sodium bromide in crystal form
  - Standard bromide solutions of concentrations of 2000 $\pm$ 50 ppm and 5.0 $\pm$ 0.2 ppm. These solutions are required for the establishing of the calibration curves as a basis for measuring the bromide concentrations in the water exchange test.
  - Four to six 100 to 200 ml beakers
  - 200 ml volumetric flasks
  - Test medium: Prepare a 4 percent, by weight, of bromide solution by diluting 51.5 grams of sodium bromide for each 1000 milligrams of distilled water.
  - Test dosage: A test dosage constitutes 200 ml of the 4 percent bromide solution which is inserted in the bowl and thoroughly mixed with a stirring rod for approximately 20 seconds.

Record the test results in a form similar to the one suggested in Table 14.

Calibrate the instrument with the prepared two solutions of known concentrations, in parts per million (ppm).

It is desirable to prepare two more solutions whose concentrations are in the range of the solutions to be used as a check on the calibration. The measured concentrations should not deviate by more than 4 percent from their actual values.

Record the data in Table 15 in the columns on "Calibration" and "Verification."

---

[1] As discussed in Section 4.3 of this report, there are numerous ways for evaluating the water exchange. A comparative evaluation of these methods is still required.

Test Run

A "test run" constitutes the following procedure which is performed for the full and partial quantity of flush for water supply static pressures of 20, 40 and 80 psi.

a. Take two readings before the run and two after its completion for a mean "background concentration."[1]

b. Make sure that the bowl is full to its weir. Add 200 ml of 4 percent NaBr solution and mix thoroughly for 20 seconds with a stirring rod.

   Take two samples from the bowl and read ppm.

   Record results in column "Ci_1"

c. Return samples to bowl. Flush the toilet. Mix water thoroughly; take two samples and read ppm. Record results in column "C_{q1}".

d. Add 200 ml of 4 percent NaBr; mix thoroughly.

e. Repeat step b and record "C_{q2}"

f. Flush toilet twice and make sure seal trap is full to its weir for the next test run pressure.

   Calculate the average value of the sample pairs and calculate:

$$R_1 = \frac{C_{q1} - C_b}{C_{i1} - C_b} \qquad R_2 = \frac{C_{q2} - C_b}{C_{i2} - C_b}$$

   Repeat the above to obtain mean values for R_1 and R_2 for each pressure. Acceptance criterion: R_1 and R_2 shall not exceed 0.04.

5.4.5 Rim Wash Test

The test shall be performed as specified in the ANSI A112.19.2 Standard Section 7.4.4.1, the Ink Test.

5.4.6 Mechanical Performance - Life Test

A mechanical assembly capable of performing the following automatic cyclic operations should be connected to the two-step flush mechanism when the latter is installed in the water closet tank:

---

[1] "Background concentration" is the concentration of sodium bromide in the water supply in the test facility at the time of testing the device.

Activate a full and partial flush cycle by tripping on the operating handle. The total time per cycle (full and partial) should equal the total filling time of the tank for a water supply static pressure of 80 psi (556 kPa). The number of flush cycles should be: 20,000 for the full flush cycle and 80,000 for the partial flush cycle.[1]

Upon termination of the Life Test, the device shall be visually inspected for the integrity of all its parts, such as fractures or deformations.

Tests 5.4.1 and 5.4.2 are then repeated.

---

1 This test simulates approximately ten years of service.

Table 13. Consistency of Water Delivered in the Full and Partial Flush Cycles

A_i - Water Usage Per Cycle - liter

Test Number	Full Flush Cycle		Partial Flush Cycle	
	20 psi-138 kPa	80 psi-552 kPa	20 psi-138 kPa	80 psi-552 kPa
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Mean - $\bar{Q}$ $\bar{Q} = \sum_{1}^{10} \frac{Q_i}{10}$	$\bar{Q}_1$ =	$\bar{Q}_2$ =	$\bar{Q}_3$ =	$\bar{Q}_4$ =
Standard deviation S $S = \sqrt{\frac{(Q_i - \bar{Q})2}{9}}$	σ_1 =	σ_2 =	σ_3 =	σ_4 =

Criterion for passing: The values for σ shall not exceed 500 ml (0.14 gallons)

Table 14. Test for Siphonic Action and Seal Trap Retention

Test for the Partial Flush Cycle

Total Pressure		1st Cycle		2nd Cycle		4th Cycle		5th Cycle
psi	Pa	Siphonic Action yes/no	Trap Seal Loss	Siphonic Action yes/no	Trap Seal Loss	Siphonic Action yes/no	Trap Seal Loss	Siphonic Action yes/no
20	138							
40	276							
60	414							
80	552							

maximum seal trap loss:

Test for Full Flush Cycle

Total Pressure		Run 1		Run 2		Run 3		4th Cycle	5th Cycle
psi	Pa	Siphonic Action	Trap Seal Loss	Siphonic Action	Trap Seal Loss	Siphonic Action	Trap Seal Loss		
		yes/no	mm	yes/no	mm	yes/no	mm		
20	138								
40	276								
60	414								
80	552								

Table 15. Liquid Wastes Removal - Water Exchange Test

Instrument Calibration and Verification

CALIBRATION	
ppm st'd solution	my reading

VERIFICATION - ppm			
Actual	Measured	Actual	Measured

Background ppm: (C_b)

P psi	Test	C_{i1}	C_{q1}	C_{i2}	C_{q2}	$R_1 = \dfrac{C_{q1} - C_b}{C_{i1} - C_b}$	$R_2 = \dfrac{C_{q2} - C_b}{C_{i2} - C_b}$
	1						
	2						
	Avg.						
	1						
	2						
	Avg.						
	1						
	2						
	Avg.						

6. CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

6.1 Conclusions

The following conclusions related to two-step flush water closet closets were derived from the laboratory test results:

- Two-step flush devices may be installed in the ordinary siphonic water closet bowls and provide satisfactory performance, provided the partial flush cycle deliver at least ten liters (2.5 gallons) of water per flush cycle (based upon the laboratory test data).

- The two-step flush devices offer a partial solution to the problems of water conservation for existing installed fixtures, and for fixtures which will be installed in the near future. These devices may save water up to 40 percent when installed in 5-gallon water closets and up to 25 percent when installed in 3.5 gallon water-saving toilets.

6.2 Recommendations

- Test procedures for performance evaluation of two-step flush devices were established and are recommended to be incorporated into ANSI 112.19.2 standard or any other standard related to water closets.

- Efficient usage of the devices may be attained if their design is compatible with the characteristics of the bowl and the ball cock in the tank into which they are installed. A necessary feature to be introduced to the system is a bowl refill control, so designed that its flow rate or total flow would be dependent on the cycle mode, such that a partial flush cycle will be followed by a larger refill flow rate (or total flow). This arrangement will refill the bowl at all times, and preserve the integrity of the consecutive flush cycle.

- The large water consumption to the U.S. made water closets is attributed to their present design stemmed from dimensional requirements of a large water surface in the bowl and a deep trap seal. Other factors are a result of consumer habits, life style and vogue. These features require a large flow during the flush cycle and a large quantity of water for bowl refill (up to three liters). A redesign of the conventional water closet where the geometry of these features will be reduced can contribute to a substantial reduction of water consumption.

- The two-step flush devices offer a partial solution to the problems of water conservation for existing installed fixtures, and for fixtures which will be installed in the near future.

- For more substantial water conservation measures, manufacturers and consumers should consider the introduction of the world-wide commonly used European Flush Down water closets. Ordinary flush down toilets require nine liters (2.4 gallons). Some water closets operate adequately with six liters (1.6 gallons) and some innovative water closets operate with three liters.

6.3 Research

- Water Exchange in Low Flush Water Closets. As specified in the revised ANSI A112.19.2M-1980 Standard, "the water exchange shall affect a dilution ratio of at least 100." No information is available whether this dilution ratio is necessary or sufficient in terms of disease transmission potentials. It is expected that the "dilution ratio" will be much lower in low flush toilets. A study is therefore required for establishing the "safe dilution ratio" so that low flush, water conserving toilets can be evaluated for biological safety levels.

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Appendix A. Description of the Two-Step Flush Devices Tested

The following devices were acquired through manufacturers and distributors of sanitary appliances:

Sample M_1

The mechanism is composed of a flapper valve which replaces the ordinary valve in the existing flush valve assembly.

The valve consists of the following parts:

1. Bulb (cup) - see Figure a

   The bulb contains a 1/4" steel ball and a 3/16" hole at its bottom. A lid containing four holes ranging in size from 1/32" to 1/8" is connected to the bulb's base. The orientation of the holes in reference to the bulb's hole determines the quantity of water flowing out in a flush cycle.

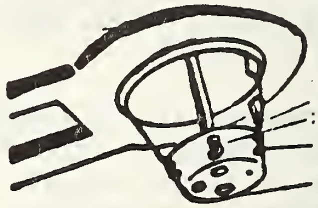

Figure a.

2. Ring and Collar - see Figure b

   The valve is connected to the flush mechanism by sliding its ring through the overflow pipe such that it rests on the overflow pipe base.

3. Chain

   The chain's hook is connected to the flush mechanism's lift arm.

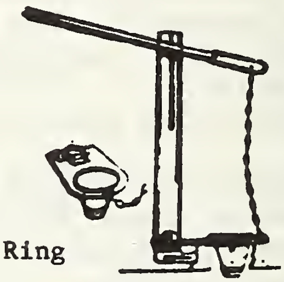

Figure b.

Figure 8.

Valve's Operation

Prior to normal operation, the valve has to be tried for its optimum performance by setting the bulb's lid to its various position until a satisfactory flush is attained.

Attaining a Partial Flush

The flush handle is depressed as with an ordinary flush mechanism and released. In this flushing mode, the (upward) buoyant force on the valve is stopped and the valve falls down prematurely with the tank retaining part of its water.

Attaining a Full Flush

The flush handle must be slowly depressed and released. This mode of operation will empty all the contents of the tank.

Sample M_2

The mechanism replaces the ordinary flush valve and the flush handle assemblies in the water closet tank. The system is composed of the following parts:

Rubber Valve (V)
Beads (B)
Float (F)
Float Catch (C)
Existing Overflow Pipe (OF)
Valve Positioning Adjuster (P)
Disc (D)
Control Arms (A_1, A_2)
Flush Handle Mechanism (H)

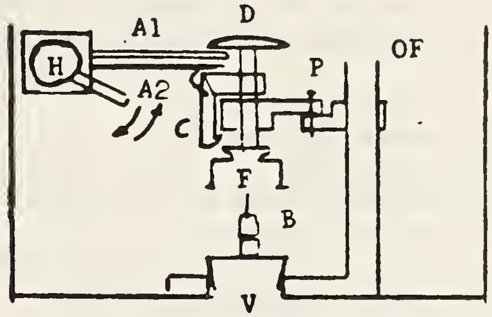

Figure 9.

Valve's Operation

In its rest mode, float (F) is in its uppermost position and kept in place by the hook at the end of the float catch (C).

Attaining a Partial Flush

The pull of the handle down will raise arm A_2, which, in turn, will raise valve (V) and at the same time the float catch (C) will release float (F). The float will drop to the descending water level, will press on valve (V) and cause an early closure, thus attaining a partial quantity of flush. When flushing ceases, the ascending water in the tank raises the float until it is locked in place by the float catch. The number of beads above the valve control the float travel distance and consequently the partial flush quantity.

Attaining a Full Flush

A pull of the handle down will raise arm A_1, which, in turn, will raise valve (V) to empty all the tank's water content.

Sample M_3

This mechanism replaces the whole flushing mechanism in the existing W.C. It is composed of the following parts:

1. Flush handle (H)
2. Handle linkage (L)
3. Brace (B)
4. Rubber valves and overflows (V_1, V_2)
5. Valves' chamber

Mechanism's Operation

The mechanism contains two valves and overflow arrangements which differ only by the valve's height relative to the water line in the tank.

Attaining a Parrial Quantity of Flush

By pushing handle (H) down, the handle linkage (L) transforms the motion to brace (B) which lifts valve V_1 from chamber C.

Attaining a Full Quantity of Flush

An upward movement of (H) lifts V_2 from C to deliver a smaller quantity of flush water.

Installation of the mechanism requires the removal of the tank so that chamber C can be connected.

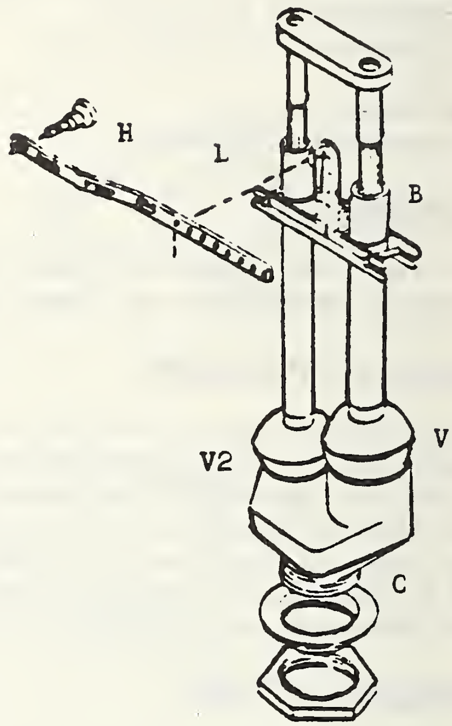

Figure 10.

Sample M_4

The device is composed of the following parts: (see figure)

1. Operating handle and rod
2. Shaft and chain
3. Valve (of elastomeric material)
4. Fastener (connection to the overflow)
5. Two floats assembly

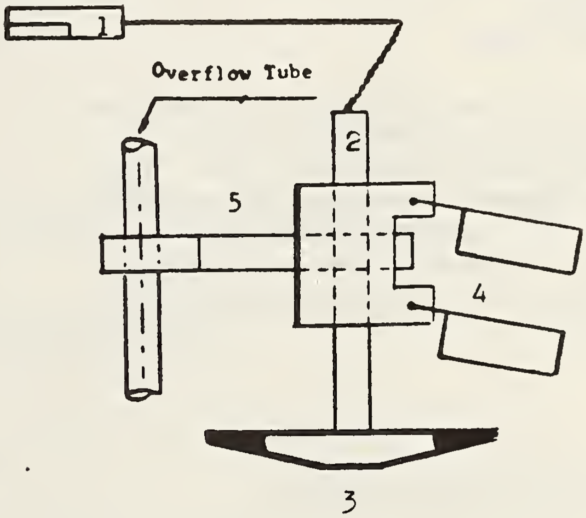

Figure 11.

The operating handle (1) replaces the existing handle in the tank. It contains two actuating controls. The long sweep control will lift the shaft (2) higher than the short sweep control. The fastener (5) is connected to the existing overflow valve at an elevation which facilitates proper functioning of the system and proper closure of the valve. When the tank is full, the buoyancy keeps the two floats (4) up.

Attaining a partial flush

When the short sweep control arm is actuated, the valve will be raised to the lower position. As the water in the tank drops below the upper float, early closure of the valve will take place for the partial flush cycle.

Attaining a full flush

When the long sweep control arm is actuated, the valve will be raised to the higher position, and will remain there until the full flush cycle ends.

Sample M_5

The device is composed of the following parts: (see figure)

1. Operating handle
2. Air hose
3. Flapper valve
4. Chain
5. Two floats

Except for the existing overflow tube, this device replaces the entire flushing mechanism of the tank. The handle contains controls for obtaining a full and a partial flush cycle. The floats may be moved to any level for obtaining the desired quantities of flush.

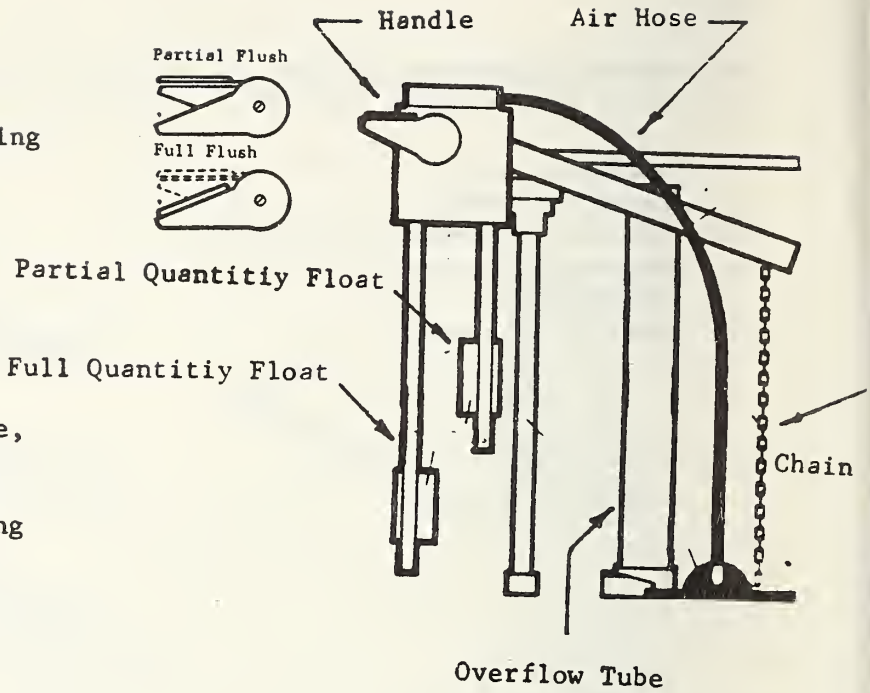

Figure 12.

Attaining a Partial Flush

The front section of the handle is pressed down (see figure). This action releases the partial quantity float mechanism. As the water level reaches this float, air from the flapper valve rushes out and allows the flapper valve an early closure for obtaining a partial flush cycle.

Attaining a Full Flush

Both sections of the handle are pressed down. This action bypasses the upper float and retains the flapper valve in an open position which enables a full flush to take place.

Appendix B. B.1 - Table 16. Water Exchange Test

Detection of Color in the Water Closet Bowl by Visual Examination

Test Procedure

Test medium: Erio Yellow T Supra, Acid Yellow, 023
Consol 19140, manufactured by CIBA-GEIGY
This medium was diluted with water to a concentration of 1:200 to simulate the color of urine from which solutions were prepared of the following concentration in reference to the above.

Solution A - 0.0000 - clear water
Solution B - 0.0010
Solution C - 0.0025
Solution D - 0.0050
Solution E - 0.0100

Two 200 ml samples were prepared for each subject (A_1 .. A_8). These 10 samples were inserted randomly in the bowl and each subject was asked whether he detected a change in color in the bowl, by:

yes - response to positive detection of dye
no - response to negative detection of dye
? - "not sure"

	Sample									
	A		B		C		D		E	
Person	1	2	1	2	1	2	1	2	1	2
A1	no	no	no	no	no	no	yes	?	yes	yes
A2	no	no	no	no	no	no	yes	yes	yes	yes
A3	no	no	no	no	no	no	no	no	?	?
A4	no	no	no	no	no	no	?	no	yes	yes
A5	no	no	no	no	no	no	yes	no	yes	yes
A6	no	no	?	?	yes	yes	yes	yes	yes	yes
A7	no	no	no	no	no	no	yes	no	yes	yes
A8	no	no	no	no	yes	yes	yes	yes	yes	yes

Note: This test merely represents an indication and in no way is intended for drawing general conclusions.

Appendix B2.

Table 17. Comparison of "R" Value Results from Different Initial Concentrations

$$R = \frac{C_q - C_b}{C_i - C_b}$$

I = NaCl concentration of 200 ml test medium
C_b = Background concentration
C_i = Concentration before flushing
C_q = Concentration after flushing

I % NaCl 200 ml	C_b PPM in bowl	C_i PPM With Sam	C_q PPM After Flush	C_i-C_b	C_q-C_b	$R=\frac{C_q-C_b}{C_i-C_b}$
1	37.4	596	56.1	488	18.8	0.038
2	32.8	946	66.6	913	33.7	0.037
3	35.7	1346	82.8	1310	47.1	0.036
4	35.6	1878	103.9	1842	68.3	0.037

Sample: B_1, Testing a partial flush cycle with 2.3 gallons of water usage. The results are means of four tests.

Appendix B3. Water Exchange Test - Errors in Measuring Sodium Bromide Solutions

Comparison betweeen prepared (known) solutions and measured solutions.
C_p - prepared solution; cm measured solution

$$\varepsilon = \frac{Cm - Cp}{Cp} .100$$

$$\varepsilon = \sum_{i=1}^{30} C_i/30; \quad S = \sqrt{\frac{\Sigma (\varepsilon_i - \varepsilon)^2/}{30}}$$

Note: This information is depicted from the test data obtained during the period of testing the two step flush data.

Low Range			Medium Range			High Range		
Cp	Cm	ε	Cp	Cm	ε	Cp	Cm	ε
3.67	3.50	-3.42	121.1	119.4	-1.32	1331.9	1353.8	+1.64
3.67	3.65	-0.54	121.1	116.5	-3.80	1598.3	1660.0	+3.86
3.67	3.68	+0.27	121.1	126.6	+4.54	1598.3	1666.0	+4.24
3.67	3.78	+3.00	121.1	126.2	+4.04	1598.3	1675.9	+4.86
2.33	2.20	-5.90	121.1	125.4	+3.55	1141.6	1195.0	+4.70
0.88	0.91	+3.30	121.6	116.5	-4.19	1141.6	1073.4	-6.42
0.88	0.83	-5.68	121.7	119.6	-1.73	1141.6	1067.9	-5.95
0.88	0.84	-4.54	190.6	182.0	-4.51	1331.9	1289.0	-3.75
3.15	3.04	-2.53	121.1	121.5	+0.33	1331.9	1355.4	+2.52
3.15	3.20	+1.58	121.1	116.0	-4.21	1141.6	1078.8	-5.59
3.15	3.06	-3.49	121.1	116.0	-4.21	1598.3	1601.8	+0.22
2.54	2.49	-1.96	207.6	213.2	+2.69	1141.6	1157.4	+1.38
2.54	2.44	-3.92	207.6	198.9	-4.23	1141.6	1162.9	+1.87
3.15	3.20	+1.58	108.3	103.5	-4.43	1331.9	1336.3	+0.33
2.54	2.77	+5.11	108.3	110.4	+1.94	1141.6	1168.0	+2.31
2.54	2.78	+5.12	108.3	109.2	+0.83	1331.9	1301.5	-2.28
2.54	2.79	+6.84	108.3	113.1	+4.47	1331.9	1293.1	-2.91
2.54	2.74	+6.84	108.3	101.3	-6.46	1141.6	1107.6	-2.98
2.54	2.74	+6.84	108.3	101.3	-6.46	1141.6	1107.6	-2.98
2.54	2.60	+2.36	108.3	118.5	+7.40	1141.6	1201.2	+5.22
2.54	2.60	+2.36	108.3	118.5	+6.40	1141.6	1208.0	+5.82
1.57	1.48	-5.73	108.3	100.3	-7.41	1141.6	1199.9	+5.10
1.57	1.45	-5.64	108.3	117.6	+8.59	1331.9	1332.5	+0.05
2.54	2.56	+0.79	108.3	117.6	+3.97	1141.6	1198.2	+4.96
2.65	2.54	+4.33	108.2	112.6	+3.97	1331.9	1392.2	+4.66
2.55	2.54	+0.39	108.2	112.9	+4.34	1331.9	1275.0	-4.27
2.54	2.59	+1.97	108.2	117.4	+6.50	1598.3	1547.6	-3.17
3.15	2.98	-5.39	121.1	124.1	+2.47	1331.9	1403.9	+5.41
3.15	3.19	+1.26	190.6	193.6	+1.57	2283.3	2354.5	-3.10
3.15	3.16	+0.32	202.8	206.8	+1.97	1141.6	1180.0	+3.47
2.54	2.73	+7.48	202.8	198.9	+1.92	1331.9	1327.2	-0.20
ε		0.21			1.11			0.73
S		4.11			4.34			3.89

B.4 Derivation of the Equation for Water Exchange

The water exchange in the bowl may take place with the following modes:

1. Piston Action

The fresh water coming from the tank completely displaces the contaminated water in the W.C. well.

Defining:

W - Volume of water in the bowl

V - Volume of water flowing to and from the tank

C_i - Initial concentration in the bowl

C_q - Final concentration of the bowl upon termination of the piston action

C_o - Concentration of the fresh water

Expressing the conservation of the mass contaminants:

$$V \cdot C_o + WC_i = WC_q + VC_i$$

$$C_q = \frac{W-V}{V} \cdot C_i + \frac{V}{W} \cdot C_o \text{ for } V < W$$

$$C_q = C_o \quad \text{for } V \geq W \quad \text{(Complete removal of contaminants)}$$

This mode of flushing represents the ideal case since the fresh water will completely replace the contaminated water as long as the volume of the incoming water is equal or larger than the volume in the well.

2. Complete Mixing Prior to Discharge

$$V \cdot C_o + W \cdot C_i = (V + W)\ C_q$$

$$C_q = \frac{V \cdot C_o + W \cdot C_i}{V + W}$$

3. Complete Mixing With Fresh Refill Water Upon Termination of Siphonic Action

Upon termination of siphonic action, the water in the bowl is W_s and its concentration C_s. The refill tube replenishes the well to a final volume of W, less or equal to the total capacity of the bowl defined as W_o.

$$4.\quad C_t = \left(W_o + \int_{t-t_o}^{t=t-\Delta t} Q_{in}\, dt - \int_{t-t_i}^{t=t-\Delta t} Q_{out}\, dt\right) \cdot C_{t-\Delta t} + V_{in} \cdot 0 - V_{out} \cdot V_{out} \cdot C_{t=\Delta t}$$

$$W_o + \int_{t=t_o}^{t=t} Q_{in}\, dt - \int_{t=t_i}^{t=t} Q_{out}\, dt$$

Assume the following events:

a. As flushing starts, unknown quantity of water flows with the initial concentration by piston action, followed by the process of instantaneous mixing described by expression 4.

   This unknown quantity, which is evacuated from the bowl by piston action, will be expressed by insertion of a consent to be evaluated on the basis of the laboratory data.

b. When the siphonic action ceases, the water remaining in the bowl undergoes the mixing process with the fresh refill water as described in Process 2.

With disregard to the intermediate processes, the integrals in Equation 4 are substituted by "W"$_x$ to be evaluated by the laboratory data:

$$5.\quad C_t = \frac{(W_o - W_x)\, C_t - \Delta V_{out} \cdot C_{t-t}}{(W_o - W_x)}$$

$$6.\quad \frac{C_t - C_{t-\Delta t}}{C_{t-\Delta\, t}} = \frac{-\Delta v}{W_o - W_x}$$

In differential terms:

$$7.\quad \frac{dc}{c} = \frac{dv}{(W_o - W_x)}$$

The solution of Equation 7:

$$8.\quad C = K\, e^{-V/(W_o - W_x)}$$

for $V = 0$, $C = C_o$

$$C_s = C_o e^{-V_s/(W_o - W_x)}$$

V_s is the flow volume to the bowl and C_s the concentration in the bowl upon termination of the mode of instantaneous mixing. Let V_o be the total flow to the bowl. Then $V_s = KV_o$, where k is some unknown fraction.

Substituting the expression for "case 3", of complete mixing upon termination of the siphonic action:

$$9. \quad C_f = C_o K_1 (W_o/W) \, e^{-Vs/(W-W_x)}$$
$$= C_o K_1 (W_o/W) \, e^{-Vo/(K_2 W_o)}$$

Let $R_1 = C_f/C_o$ the relative concentration ratio

$$10. \quad R_1 = K_1 \, (W_o/W) \, e^{-Vo/(K_2 W_o)}$$

K_1 and K_2 are constants which are evaluated from the laboratory test data, with the "least square" method by minimizing the following expression

$$\sum_{i=1}^{n} (R_{i_{laboratory}} - R_{i_{equation}})^2 = E$$

$$\Sigma \, (R_{i_{laboratory}} - K_1 (W_o/W) \, e^{-Vo/(K_2 W_o)})^2 = E$$

Another scheme may be used for minimizing the following ratios

$$\Sigma \; \frac{R_{i_{laboratory}} \; R_{i_{equation}}}{R_{i_{laboratory}}}^{2} = E$$

As the values of R range from 0.1 to 0.0001, the first scheme tends to minimize the discrepancies of the large values obtained by the expression and the second scheme has a tendency to minimize the small values.

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