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A Rational Approach to the Design of Water Closet Bowls

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Numerous types of water closets are in the market today in India. These water closet bowls or pans can be used with several types of flushing devices. By experience it has been seen that there are numerous complaints of improper functioning of W.C. bowls and consequent large scale wastage of water due to repetation of flushing. This paper gives a brief description of different types of water closets and flushing devices. Rational approach to the testing of efficiency of W.C. bowls and to their hydraulic designs are covered in greater detail in this paper. Recommendations for the size and shape of the water seals, shape of the interior of the bowl are also given. It is important to note that a maximum of 75 cm² area of water seal is permissible in W.C. bowls for efficient performance, while the IS: 2556 recommends a minimum of 150 cm² area. Modified W.C. bowls with reduced water seal areas give satisfactory results even with 6 litre flushing cistern. These investigations show a way for considerable savings in treated water by adopting low capacity flushing cisterns with rationally designed W.C. bowls.

Present Status

NUMEROUS types of water closets are in the market today in India. All these types can be broadly said to be either Indian squatting type or Western commode type. Normally the Indian squatting type is called as W.C. pan and Western commode type as W.C. bowl. The further subclassification of each type is only due to the changes in their shape and profile of the interior, and exterior appearance. Normally circular water seal surfaces are employed in the W.C. pans and rectangular onces in W.C. Bowls. Even in the area of water seal surface there are wide variations from make to make.

Any type of W.C. bowl/pan can be used with any kind flushing cistern. The flushing cisterns can be broadly

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classified as either siphonic action type or valve operating type. The latter valve type may cause flow, during the discharge, due to pressure in the feeding line (called as flushing valves), or due to the head of water above the valve fitting in the flushing cistern (called as valve type flushing cistern). Any mechanical flaw in the valve will cause a continuous leak, directly draining to the W.C. bowl/pan. Such leaks normally go unnoticed and result in large scale wastage of water. For this reason the Indian standard specification for Flushing Cisterns for Water Closets and Urinals (I S: 774-1964) recommends the flushing cisterns working only on siphonic principles and forbids the use of valve type. The flushing cisterns can be again classified as high level, low level, and intergrated depending on the height of location above the W. C. bowl/pan. Normally the capacity of these tanks are 15 litres (3 gallons). But these days even 10 litre capacity flushing cisterns are in the market, but of only high level type and these are approved by the IS: 774.

Conventionally Indian squatting type W.C. pans are used only with high level flushing cisterns. The experiences of these W. C. pans in the field are satisfactory even with 10 litres flushing cisterns. But the field reports on the commode type W. C. bowls of Indian manufacture is rather discouraging. There are many complaints of inefficient functioning and consequent large scale wastage of water due to repeated flushings. This paper deals with the investigations on the causes and remedies of malfunctioning of W.C. bowls.

Efficiency Test

Conventional test for the efficiency of W.C. bowl is called the 'paper test'. In this test, six pieces of loosely crumpled toilet papers of approximately 150 mm x 115 mm in size are charged on the surface of water seal. For an efficient bowl, in four flushings at least thrice full charge of the paper should be discharged. This test is also prescribed in I.S. specification for vitreous sanitary appliaces (IS: 2556). In the laboratory trials conducted at Central Building Research Institute, it has been seen that the results of efficiency test, conducted as detailed above, varied from zero to even cent per cent for a given constant set up. The reason for such erratic results may be due to variations in the degree of crumpling and time allowed for the paper to absorb water. Even the quality of the paper can have significant effect on the efficiency test result. Therefore a more reliable testing procedure which gives consequent concurrent results, for a given set up, was required. This was essential for any meaningful investigation on the functioning of W.C. bowls. For this purpose number of trials were carried out with various materials of different shapes as charging material on the surface of water seal. Finally it was seen that the use of 50 numbers of Polyethylene balls of 18 mm diameter and of 0.84 specific gravity offers a more reliable testing procedure. The efficiency of W.C. bowl is given by the number of balls flushed out expressed as per cent of the 50 number of balls charged initially. This testing procedure has been used throughout the investigation for evaluating the W.C. bowl.

Investigations

Different makes of W.C. bowls that are manufactured in India were considered for initial investigation of their efficiency. Efficiency tests were carried on the chosen W.C. bowls in combination with both high level and low level flushing cisterns of 15 litres capacity. Both siphonic and bell type flushing cisterns were tried. Incidentally bell type flushing cistern also works on siphonic principle, but the design of cistern incorporates a movable bell in places of the siphon chamber and the plunger plate of the siphonic type flushing cistern. At the time of investigation only bell type 10 litre capacity flushing cisterns were available. The results of the initial investigation on the efficiency are given in Table I.

The above Table I clearly shows that siphonic type flushing cisterns give better results than bell type in combination with any type of W.C. bowls. It also shows that 15 litre capacity cistern always performs better than 10 litre capacity ones.

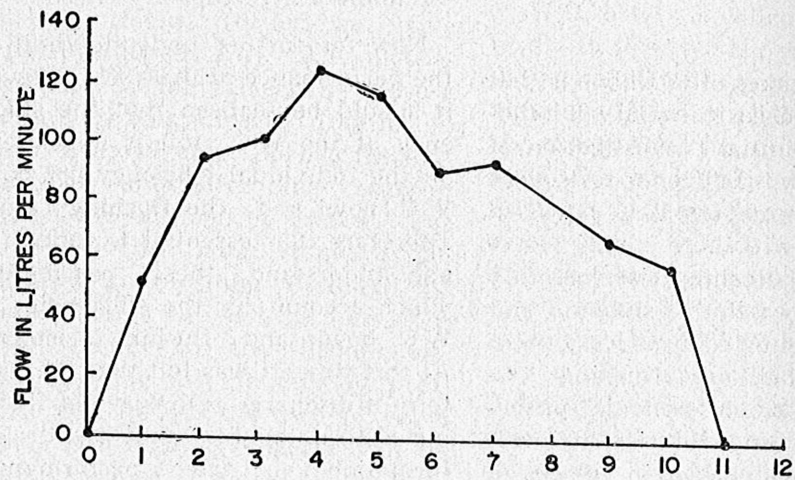
Now for further understanding of the performance of these W.C. bowls, it should be realised that the efficiency of the W.C. unit is dependent on the individual efficiency of both W.C. bowl and the flushing tank. Therefore it is essential to indentify and understand these parameters which account for the efficiencies of W.C. bowls and flushing cisterns. At this time, it was felt that the pattern of discharge rate curve of flushing cisterns might reveal greater information on their performance, than revealed by total capacity. Hence the rate of discharge at every second during the discharge through the tail end of the flush pipe of all types of flushing cisterns were noted. The discharge rate curves of high level, 15 litres capacity flush-

TABLE I

Sr. No.	Make	Flushing Device	% Efficiency
1	A	10 litre Bell type	5.4
2	B	—do—	39.0
3	C	—do—	64.6
4	A	15 litre Bell type	32.0
5	B	—do—	43.8
6	C	—do—	85.0
7	A	15 litre Siphonic type	64.6
8	B	—do—	65.4
9	C	—do—	99.4

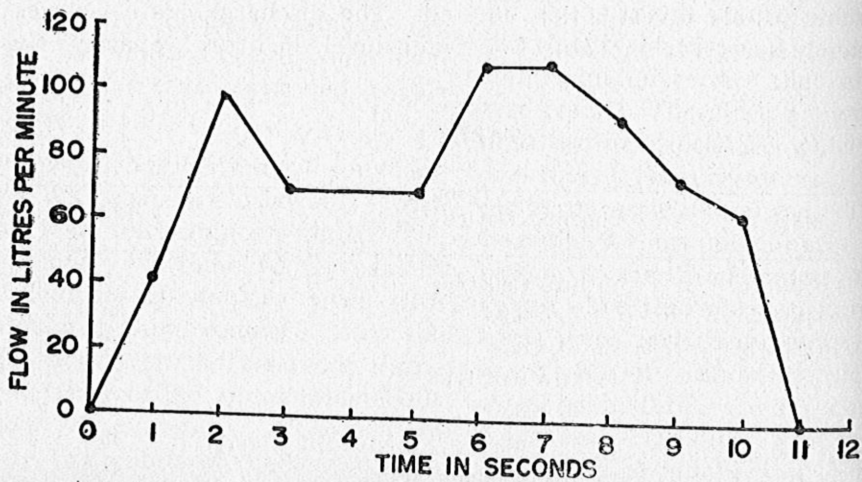
ings cisterns of siphonic and bell types are shown in Figures 1 and 2 respectively. Similar curve for high level 10 litres capacity flushing cistern of bell type is whown in Fig. 3.

The discharge rate curves of bell type flushing cistern (Fig. 2) shows two peaks for rate of flow. It is seen that the first peak occurs within the first 2 to 3 seconds of time. This



3 GALLONS SIPHONIC TYPE FLUSHING CISTERN ACTUAL DISCHARGE-15 L

Fig. 1



3 GALLONS BELL TYPE FLUSHING CISTERN (HIGH LEVEL) ACTUAL DISCHARGE-13·5 L

Fig. 2

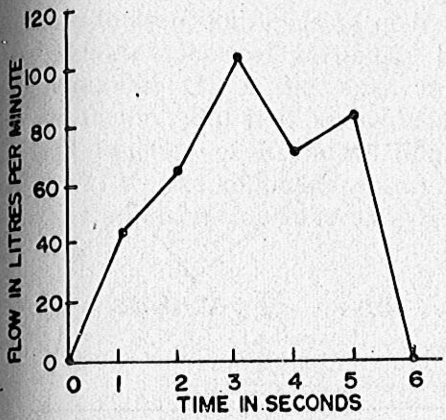


Fig. 3—2 Gallons Bell Type Flushing Cistern (High Level)

peak could be said to have originated due to the manual lifting of the bell. Therefore mode of pulling the chain, which varies from man to man and time to time, considerably influences this peak value of discharge. This zone of discharge rate curve having the first peak can be termed as mechanical ozone, which in turn seeds the siphonic action. But there is definite transition period before the siphonic action completely sets in. The peak rate of discharge achieved in the siphonic zone is considerably more than the first peak It is this latter peak rate of flow which accounts for the efficiency of flushing cistern. However, in 10 litres capacity flushing cistern of bell type (actual discharge being only 7 to 8 litres) the two peaks are not clear.

In case of siphonic type flushing cistern there is only one peak which is normally reached within 4th to 6th second from the start of the flush. For this reason the siphonic flushing cistern can always give greater peak and hence more efficient. Also in bell type flushing cistern there are chances of the failure of mechanical zone to seed the siphonic action due to improper pulling of the chain. This possibility of uncertain flushing at times is definitely a disadvantage of the bell type flushing cistern. Moreover the bell type causes considerable noise while operating, whereas the siphonic type is comparatively noiseless in operation. Therefore it will not be wrong to discourage to use of bell type flushing cisterns, though siphonic type cisterns are slighly costly.

The most important parameter for the efficiency of the W.C. bowl is the rate of flow through the water seal trap in W.C. bowl, caused by the flushing cistern. Therefore observations were also made for peak rate of discharge through W.C. bowls of different makes in combination with the flushing cisterns already calibrated. Figure 4 shows the discharge rate curve through W.C. bowl 'A' in combination with a 3 gallon bell type of flushing cistern, which is one of the least efficient combinations. The peak rate observed in this case was 90 litres/minute. Hence for future design features of any W.C. bowls a minimum of 90 1/min of peak flow through the bowl could be safely assumed to be available. This 90 1/min flow may be exceeded. but never would be lesser.

Hydraulic Design

The criteria for the design of an efficient W.C. bowl should be that during flushing it offers a speedy and complete removal of the sus

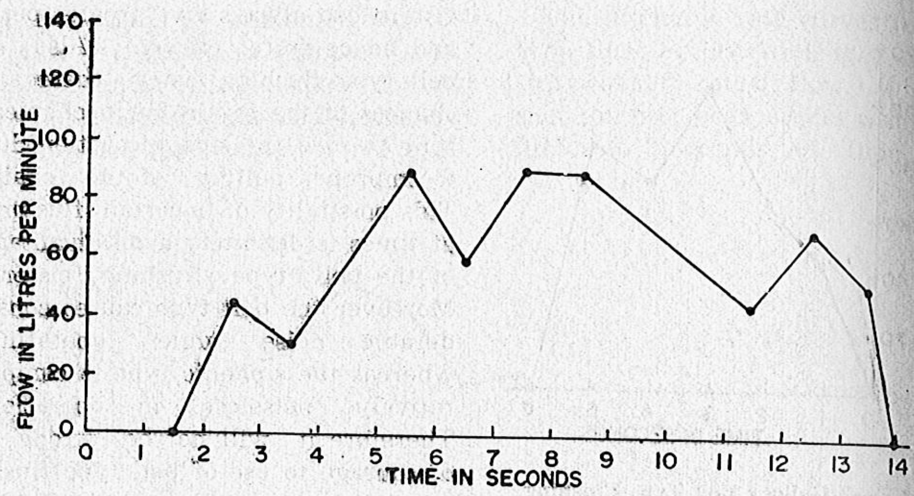


Fig. 4—Discharge Through Water-closet 'A' With Bell Type 3 Gallons Flushing Cistern

pended particles in the water seal. That means the area, shape and volume of the water seals of W.C's are very vital. It is interesting to note that the Indian Standard specifications for Vitreous Sanitary Appliances (IS: 2556—1963) recommends a minimum area of 150 cm^2 for the water seal surface. The reasoning given for this recommendation is 'from hygienic angle'. While realising that too small a surface area would certainly cause 'unhygenic' condition, the arbitrary decision on the minimum area appears to be unacceptable. Also it could be shown that the water seal area requirement is governed by the velocity of water to drag out all the suspended particles, from the efficiency point of view. The theoretical drag velocity V_D is arrived at by the equation (1) taken from the hydraulic sedimentation theories :

$$V_D = \sqrt{4/3 \frac{g}{C_D} (1-S_s) d} \quad \ldots \quad (1)$$

Where

g	=	Acceleration due to gravity
S_s	=	Specific gravity of particle
d	=	Diameter of the particle.
C_D	=	Newton's drag coefficient

The above general equation is applicable for settling or rising of free and discrete spherical particles. In this equation C_D is the only unknown factor. But it is known that C_D is a function of Reynold's number given by the following observational relationship for spherical particles.

$$C_D = 24/R + 3/\sqrt{R} + 0.34$$

Now again R, the Rynolds number is the unknown factor and is a function of velocity of water and diameter of particle as given below.

$$R = \frac{V_D \quad d}{\nu}$$

Where ν is kinematic viscosity. Now replacing C_D in terms of V_D the equation (1) could be rewritten as equation (2).

$$V_D = \sqrt{\frac{4}{3} \frac{g}{\left(\frac{24 \ \nu}{V_D . d} + \frac{3 \sqrt{\nu}}{\sqrt{(V_D . d)}} + 0.34\right)} (1\text{-}Ss)d} \quad \ldots \quad (2)$$

Further, taking ν at 30°C as 0.804, d as 1.8 cm and Ss as 0.84 (as specified in polythylene balls test) the equation (2) could be simplified and rewritten as equation (3).

$$V_D = (1 + 0.188 \sqrt{V_D} + 0.0317 \quad V_D) = 34.6 \quad \ldots \quad (3)$$

Solving for V_D by trial and error, the value of V_D is 16 cm/sec. Thus theoretically for discharging all the suspended particles (ie cent per cent efficiency), there should be a minimum velocity of 16 cm/sec., through water seal during flushing. However, assuming a factor of safety of 1.25 to account for field flaws, the recommended velocity requirement through W.C. water seals is 20 cm/sec. Hence considering a minimum of 90 1/min of flow through the water seal and 20 cm/sec velocity through it, the permissible maximum area of water seal is 75 cm^2. Thus it could be safely said that the area of water seals in W.C. bowls should not be more than 75 cm^2 for efficient performance in all circumstances.

With this back-ground, it would be worth while to compare the water seal surface areas of different W.C. bowls studied. The Table II given below shows such a comparison.

It could be seen from the above table, that the W.C. bowl 'C' has the least area of water seal. It is also relevant here to restate that the W.C. bowl 'C' is also the most efficient one, as seen from Table I. Also while reading Table II in conjunction with the informations of Table No. 1, it could be said that as the area of water seal surface of W.C. bowl decreases, the efficiency of the bowl increases. It was also noted that the shape of W.C. bowl and volume of water seal also have bearing on the performance of W.C. bowls. A mere adherence to the recommendation of water seal area alone may not give better results unless the shape of the bowl and trap are also considered, as described in the following para.

The interior of bowl just above the water seal surface shall be vertical, at least for 50 to 75 mm. Any inclined profile in this region will cause cross currents and reduce the effective drag force of the flow. There shall not be any sharp corners and sudden restrictions in water seal passage to facilitate smooth flow. The volume of water in trap shall be as little as little as possible to maintain a minimum of 50 mm deep water seal. Small quantity of water offers greater dilution ratio and easy washing out of particles. An ideal and rational designs of W.C. bowl is shown in Fig. 5.

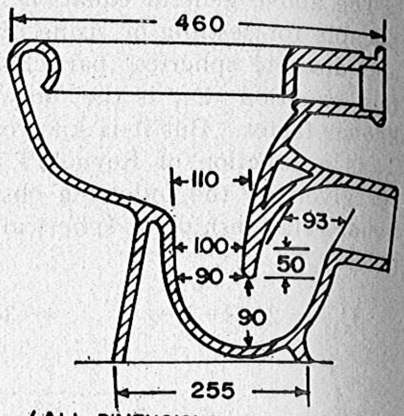


Fig. 5—An Ideal Water-closet Bowl

Confirmatory Experiments

To confirm the fitness of the above recommendations, the W.C. bowl 'A', which is the least efficient has been taken for modifications. This had a water seal area of 225 cm². It was essential to reduce the area of water

TABLE II

S. No.	Make	Water seal area in cm²	Volume of water in trap in litres
1	A	225	2.8
2	B	209	2.4
3	C	165	1.79

TABLE III

Flushing device	Efficiency of W.C. Pan A	
	Original (Water surface Area-225 cm)	Modified (Water surface Area—156 cm²)
15 litres Bell type	32.0%	46.8%
15 litres siphonic type	64.4%	81.8%

seal and try for the efficiency of the unit in order to verify the earlier conclusions. Therefore the entire interior surface of the bowl was hacked and covered with a layer of plaster of paris, with a final coating of bitumen paint. However, the area of water seal could be reduced only upto 156 cm^2, due to practical difficulty. Also the shape was modified to suit the Fig. 5, to the extent possible. The results of test on the original and the modified bowl are given in Table III.

The above Table III shows an increase of 14.8 and 17.4 per cent in efficiency of the W.C. bowl with bell and siphonic type flushing cisterns. Similarly other types of W.C. bowls were also modified to reduce this area of water seal. In one of the units the reduction of area upto 90 cm^2 was possible. The efficiency test results of this modified unit in combination with 15 litre flushing cisterns were cent per cent. Therefore a six litre capacity high level siphonic type flushing cistern was designed and fabricated in the laboratory. This 6 litre flushing cistern in combination with modified W.C. bowl having 90 cm^2 area of water seal, gave efficiency test results as high as 85 to 90 per cent. At this stage it was necessary to subject this combination to 'scour test' using lamp black, as described in IS: 2556. The results were satisfactory. These experiments clearly indicate the feasibility of effective utilisation of low capacity flushing cisterns, which can cut down the present day requirement of flushing water by about 60 per cent. But these low capacity 6 litre flushing cisterns should be used only with rationally designed W.C. bowls for good performance.

Recommendation

1. The water seal area in any W.C. bowl should not be more than 75 cm^2.
2. In the trap design sudden changes and sharp corners are to be avoided in passage of flow.
3. The interior of bowl should be vertical at least 50 to 75 mm just above the surface of the water seal.
4. The volume of water in trap should be as little as possible, preferably not exceeding 1.75 litres.

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