10th WEDC Conference

Water and sanitation in Asia and the Pacific : Singapore : 1984

Slow sand filtration and appropriate technology

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1. INTRODUCTION

Community water supply systems have to be technologically sound, economically viable, socially acceptable and within the local capabilities to operate and maintain. Slow sand filtration is such a technology for purification of surface water in rural areas. The advantages of the process such as its simplicity, reliability and ability to produce a high quality water have been demonstrated at village level by a recently concluded research and demonstration project in India(1).

Because slow sand filters require a larger area and are usually cleaned manually, they are considered expensive and are opted out in preference to rapid filters while planning new schemes. This is not, however, always true and for many small water supplies slow sand filters are cost effective. This paper presents a rational approach to the design and construction of slow sand filters and a cost comparison between slow and conventional rapid sand filters.

2. BASIC DESIGN CONSIDERATIONS

2.1 Design Period A major constraint in the provision of water supplies in developing countries has been inadequate finances(2). When money is scarce and interest rates are high, long-range investments are less preferred to investments that bring immediate benefits. Since there is very little economy of scale in slow sand filter construction as shown by cost analysis later, the design period should be short; for example, 10 years.

2.2 Design Population and Per-capita Supply The design population should be estimated with due consideration to all factors governing the future growth and development of the community; transportation, agriculture, electrification, education and health services .

In most of the developing countries the per-capita water supply ranges between 40 and 70 lpd. A recent study (3) recommends a minimum of 70 lpcd when supply is through public stand posts and 90 lpcd when house connections are provided. The per-capita demand multiplied by an estimate of the future population gives the total design volume.

2.3 Rate of Filtration The traditional rate of filtration adopted for normal operation is 0.1 m/h (2 gph/sq.ft.). Pilot plant studies (4) have shown that it is possible to produce safe water at a rate of 0.2 m/h or even 0.3 m/h. Ofcourse, at these higher rates, the filter runs are shortened, but the treated water quality does not deteriorate. The 0.2 m/h rate is considered a maximum desirable rate during periods when some filters are out of service for cleaning or repairs. This recommendation deviates from the general practice in many developing countries of providing one extra unit so that the overload filtration rate is kept to 0.1 m/h. A design that does not allow even occasional overload seems to increase the size and cost of the facility unnecessarily .

2.4 Mode of Operation Pilot studies (5) have shown that intermittent filter operation is not desirable. A short time after start-up, the bacteriological quality of filtered water deteriorates and becomes unacceptable. Because the purification process is as much biological as physical, the biological organisms do best when conditions are nearly steady. In rural areas where continuous pumping may not be feasible, 24 hr operation of filters can be ensured by providing a raw water storage reservoir of adequate capacity to feed by gravity to the filters during non-pumping hours. This is being practised in several installations in India and has proved cost effective .

2.5 Number of Filter Beds To ensure uninterrupted production, a minimum of two filter units should be built irrespective of plant capacity. Three or more units may be required because the size of each unit can not exceed certain maximum practical dimensions, or three or more units may reduce overload on working filters when one unit is out of service for cleaning or repairs. It will be shown later that for a given area, the number of filter beds can be increased for higher flexibility and reliability for a marginal increase in cost of construction.

2.6 Filter shape and plant layout

Filters may be circular or rectangular. Circular filters are not economical except for very small installations. The common wall of two rectangular units may offset the inherent structural advantages of circular shape. Rectangular filter dimensions can be determined so that the wall perimeter for a given area and thereby the cost of construction is minimum .

2.7 Depth of filter box The elements that determine the depth of filter box and their suggested depths are: freeboard (20 cm.), supernatant water reservoir(100 cm.) filter sand (100 cm.), supporting gravel (30 cm.) and under-drainage system (20 cm.) with a total depth of 270 cm. The use of proper depths for these elements can reduce the cost of filter box considerably, without adversely affecting efficiency.

2.8 Choice of filter sand and gravel Undue care in the selection and grading of sand for slow sand filters is neither desirable nor necessary. Studies (4) have shown that builder grade sand could be as effective as graded sand and also reduce the cost of construction. Similarly, rounded gravel, which is often quite expensive and difficult to obtain, can be replaced by hard broken stones to reduce cost.

3. ECONOMIC AND COST CONSIDERATIONS

3.1 Minimum filter cost The cost of a filter excluding pipes and valves is made up of two components: the total cost for floor, underdrains, sand and gravel; and the cost of walls of the filter box .

This cost in general is :

$$C = K_A A + K_p P \qquad ... \quad (1)$$

where A is the total filter bed area in m^2, P the total wall length in m, K_A the cost per unit area of filter bed, and K_p the cost per unit length of wall.

For rectangular filters arranged in a row with common walls, the problem is to minimize C subject to:

$$A = nlb \text{ and } P = 2nb + l(n+1)...(2)$$

where n is the number of filters, b is the breadth, and l is the filter length.

The term $K_A A$ is constant for any value of n and any filter shape. Hence, the minimum cost solution is the solution that minimizes P, which is :

$$l^2 = \frac{2 A}{n+1} \qquad ... \quad (3)$$

and

$$b = \frac{(n+1)l}{2n} \qquad ... \quad (4)$$

The equation for b, when rearranged shows that $2nb = (n+1)l$, or the condition for minimum filter cost is to have the sum of the lengths equal to the sum of the breadths.

The general expression for the minimum cost is found by substituting Equations 3 and 4 for Equation 1 :

$$C = K_A A + 2 K_p (\sqrt{2A(n+1)})$$

A detailed cost estimate based on 1983 prices (Nagpur, India) and excluding contractor's profit for various materials and items of work has shown that the filter bed cost per square metre is Indian Rupees 500 and the wall cost per metre length is Rs. 830 .

Therefore, $K_A = 500$ and $K_p = 830$, the specific cost function written in terms of area A is :

$$C = 500 A + 1660 (\sqrt{2A} (n+1))$$

3.2 The cost of operating flexibility For a given area, the cost of filter media and underdrain is practically the same for any number of filter beds. However, when the number of beds is increased, the cost of construction will increase because of increased wall length. The extra cost to be paid for higher flexibility and

reliability is only a fraction of the cost of the least flexible acceptable design, which has only two filters and may often be judged a good investment. The percentage increase in cost with reference to the minimum of two filter units is shown in Table 1 .

TABLE 1 - PERCENT COST INCREASE FOR 3,4 & 5 UNITS AS COMPARED TO 2 UNITS ONLY FOR A GIVEN AREA

Area (m^2)	% Cost Increase		
	3 units	4 units	5 units
100	6.9	13.0	18.6
200	5.6	10.6	15.1
400	4.5	8.4	12.0
800	3.4	6.5	9.2
1000	3.2	5.9	8.5
1600	2.6	4.9	7.0
2000	2.4	4.5	6.4

The table of costs shows that for filter areas upto 2000 m^2, the number of filters can be raised from two to three by spending roughly 2 to 7 per cent more money. Building five units instead of two, costs roughly from 6 to 18 per cent more. The smaller the total area the greater the additional cost for building more than the minimum of two units. However, it would not be wise to build more units for small areas,

as the unit size would become too small for practical construction. Too many filters would also demand greater attention from the operator.

If it is assumed that for a given filter area, the per cent increase in cost to provide a given number of units (against a minimum of two) should not exceed a pre-determined value, (based on the cost equation $C = 500 A + 1660 (\sqrt{2} A (n+1))$), the lower limit of area A can be worked out for different values of n. The number of units for a given area and the cost thereof have been worked out for 5 per cent and presented in Table 2 which can serve as a ready recokener for a design engineer.

3.3 Economy of scale   A general cost model for the filter beds can be written as :
$$C = K(A)^a$$
where 'A' is the total area of filter beds, K(A) is the cost per unit area of filter bed construction including walls, and 'a' is the exponent that represents the economy of scale factor.

The cost data given in Table 2 has been used to determine the parameters 'K' and 'a' of the function by the method of least squares. The resulting equation is given by :
$$C = 1617 A^{0.869}$$
Slight changes in the unit cost of filter bed and box wall, from the values of 500 and 830 used to derive Table 2 do not significantly change the value of the exponent 'a' .

TABLE 2 - OPTIMAL NUMBER,SIZE AND TOTAL COST OF FILTER UNITS FOR A GIVEN AREA

Area (m^2)	Capacity* (m^3/hr)	No. of units	Length (metres)	Breadth (metres)	Total cost (Rs. in million)
100	10	2	8.2	6.1	0.09
200	20	2	11.5	8.7	0.15
300	30	2	14.1	10.6	0.22
400	40	3	14.1	9.4	0.29
800	80	3	20.0	13.3	0.53
1000	100	3	22.4	14.9	0.64
1400	140	3	26.5	17.6	0.87
1600	160	4	25.3	15.8	1.00
2000	200	4	28.3	17.7	1.23

* At a filtration rate of 0.1 m/hr .

Large economies of scale are associated with small values of the exponent. Until the exponent decreases to about 0.6 or 0.7, there is no economic incentive to overdesign. Thus, very little saving is accomplished by increasing the size of the project in order to provide service over a long time into the future. It has been shown (6) that the best economic policy in slow sand filter construction is to use initial design periods of not more than 10 years and to provide for frequent expansion to meet future demand.

3.4 Cost comparison between Slow Sand and Rapid Sand Filters

An analysis of comparative costs of conventional rapid sand filters vis-a-vis slow sand filters has been presented in this section. The costs (1983 prices) for conventional plants (flash mixer, clariflocculator and rapid sand filter) were obtained from reputed construction companies in India. Based on a regression analysis of the cost data, a model has been developed for cost of rapid sand filters (Fig.1).
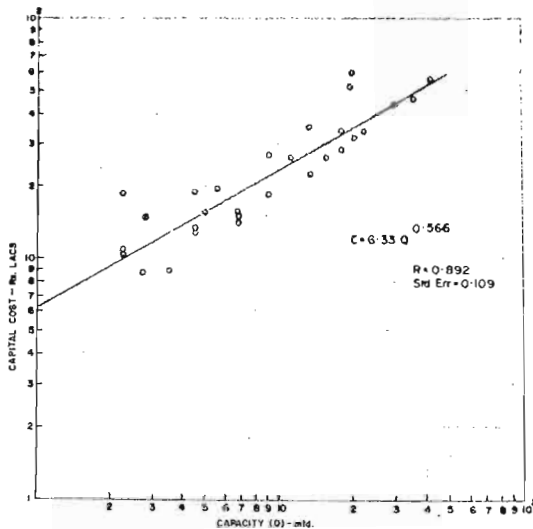
FIG 1. COST MODEL FOR RAPID SAND FILTERS.

$$C = 6.33 \, Q^{0.566}$$
$$R = 0.892$$
$$Std \, Err = 0.109$$

The costs (1983 prices) for slow sand filters with no pre-treatment have been worked out for various items of civil engineering construction including cost of land. In both the cases, the costs are inclusive of overheads and profit margin. The comparative costs thus obtained for rapid and slow sand filters are given in Table 3 .

TABLE 3 - COST OF SLOW SAND Vs RAPID SAND FILTERS

Capacity (mld)	Cost (Rs. in million)	
	SSF	RSF *
1.0	0.5	0.6
1.5	0.6	0.8
2.0	0.8	0.9
2.5	1.0	1.0
3.0	1.2	1.2
4.0	1.5	1.4
5.0	1.9	1.6
7.0	2.5	1.9
10.0	3.4	2.3
15.0	4.8	2.9
20.0	6.2	3.4

* From regression model

It can be seen from the table of costs that the capital cost of slow sand filters is less than that of conventional plants upto a capacity of about 3.0 mld. It is well established that the operation and maintenance cost for slow sand filters is always less than that for rapid sand filters. Therefore, a rational comparison has to be made on the basis of capitalised cost or total annual cost of the two systems. The capital and operation, maintenance and repair (OMR) costs for rapid and slow sand filters of different capacities have been considered and capitalised costs worked out. From the cost-capacity curves (Fig.2), it can be seen that slow sand filters are economical upto 8.0 mld., which is equivalent to serving a population of approximately 1,20,000 at 70 lpcd water supply .
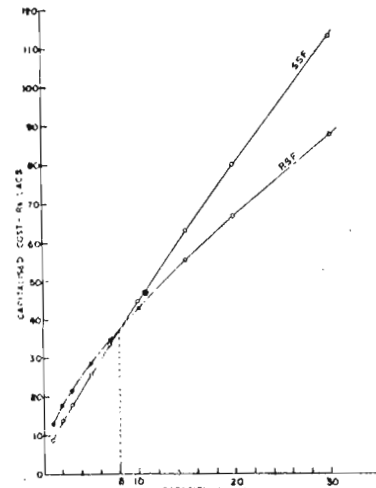
FIG 2 CAPITALISED COST FOR SLOW SAND & RAPID SAND FILTERS

Almost all the villages and towns that still remain to be covered with protected water supply in India and in many developing countries have a population of a few thousands only. Even if regional water supply schemes covering a number of villages are considered, the total population may seldom exceed 1,00,000, for which water treatment by slow sand filtration can prove appropriate and cost effective.

4. SUMMARY

In the light of recently completed research, a rational design of slow sand filters has been discussed. A cost model for filter has been suggested and it has been shown that there is no economy of scale in slow sand filter construction. Cost comparison between slow and conventional rapid sand filters has proved that for plants of capacity upto about 8 mld, slow sand filters are cheaper .

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