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THE DEVELOPMENT OF CONSTANT FLOW LIQUID DOSING EQUIPMENT WHICH OPERATES WITHOUT EXTERNAL POWER

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INTRODUCTION

In southern Africa water supply authorities have to cater for a very wide spectrum of needs varying from large-scale metropolitan to small-scale rural requirements. Water treatment technology correspondingly vary between highly mechanised and automated to simple labour intensive systems. Dosing of chemicals as an essential and integral part of most water treatment practices often poses a problem at the lower end of this scale.

Extensive monitoring records by the NIWR over a period of more than 20 years confirmed that proper disinfection and clarification remains a serious problem in some of the smaller works where operational and maintenance skills are often lacking. For small-scale water supply disinfection is normally achieved by gaseous chlorine or the manual addition of calcium hypochlorite in the form of a slurry. In this form a constant dosage from a simple device such as a gravity feed tank is rather difficult because of change in hydraulic head and blockage of discharge orifices. For more accurate dosing of slurries electrically driven dosing pumps are preferred but these also require regular supervision and maintenance.

With these constraints in mind the NIWR has developed a chemical dosing device which is simple to operate and which has good accuracy. It requires minimal maintenance and supervision and suited for dosing of calcium hypochlorite as well as metal coagulants such as alum and ferric salts. The principle involved is to maintain a constant hydraulic head during predetermined dosing time cycles.

In its simplest form it is independent of electrical power but when available it can be adapted for stepwise changes in dosing requirements or automatic shut off during power failures and plant stops.

In this paper the laboratory evaluation of a prototype unit is described and design procedures for practical applications are derived.

DESCRIPTION OF UNIT

The device essentially comprises of three containers or tanks designated T_1, T_2 and T_3 (see Figure 1).

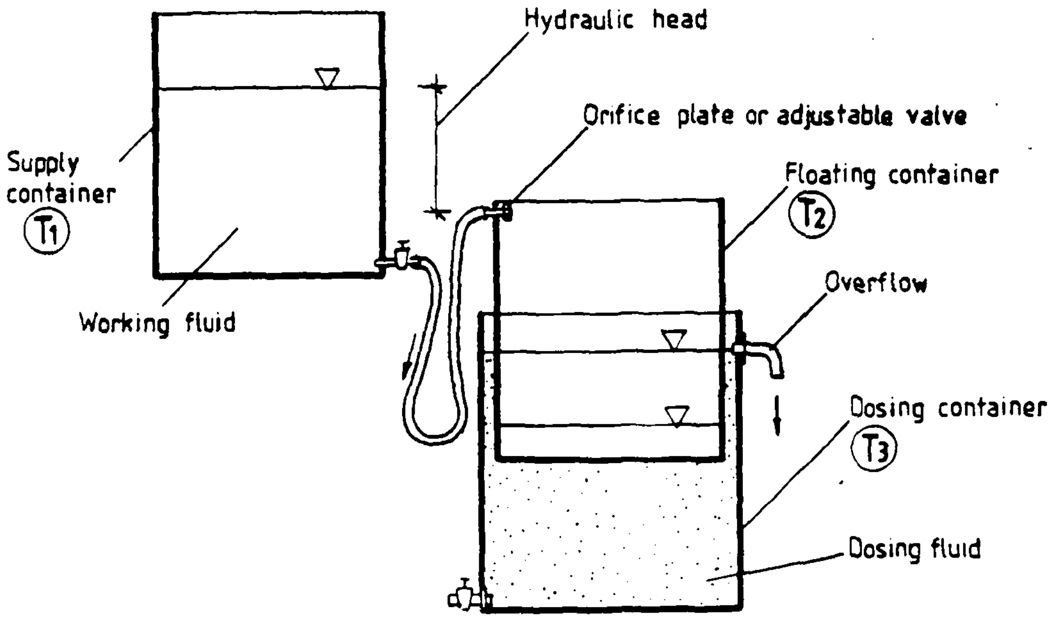

FIG. 1. CONSTANT HYDRAULIC HEAD CHEMICAL DOSING DEVICE

T_1 is filled with water which should ideally be of high clarity. This water is discharged via a flexible hose and calibrated orifice into T_2.

The initial rate of discharge can be predetermined by selection of the right orifice aperture and the choice of hydraulic head between the level of water in T_1 and the discharge level at T_2. The discharge rate from T_1 can therefore be flexibly selected from a particular orifice aperture and variable discharge head. Because pure water of low turbidity is used the risk of blocking the orifice even at very small apertures is eliminated.

T_2 serves as a recipient container for the water discharged from T_1. It also serves as a float chamber immersed in T_3 which contains the dosing chemical. T_2 is vented to atmosphere for obvious reasons and also equipped with a syphon which becomes operative at the end of a dosing cycle.

The dosing container T_3 is fitted with an overflow through which chemical solution is discharged as a result of gravity displacement by T_2.

BASIC PRINCIPLES

The dosing unit is essentially designed to maintain a constant head which is preselected at the beginning of a dosing cycle. For this purpose the internal diameter of T_1, the external diameter of T_2 and the density of the dosing liquid ρl are of overriding importance. By simple arithmetics the following basic formulae can be derived:

$$\frac{\Delta H_1}{\Delta H_2} = \frac{D_2^2 \times \rho l}{D_1^2 \times \rho w}$$

Where ΔH_1 = change of level in T_1 in unit time

ΔH_2 = change of discharge level of T_2

ρl = density of dosing liquid

ρw = density of water taken as unity

D_1 = internal diameter of T_1

D_2 = external diameter of T_2

D_3 = internal diameter of T_3

For maintenance of a constant hydraulic head $\Delta H_1 = \Delta H_2$

Therefore $D_2^2 \times \rho l = D_1^2 \times \rho w$

It is evident that ρl plays a significant role in the selection of D_1 and D_2. For practical cases where ρl is close to unity D_1 and D_2 can be equated without sacrificing too much accuracy.

Another design parameter of relevance but less critical from a design point of view is D_3 which should be greater than D_2 in order to allow buoyancy clearance. In addition the heights and volumes of the three containers are related in accordance with the formulae derived in the section dealing with design steps.

TESTING OF PROTOTYPE UNIT IN THE LABORATORY

A small-scale prototype unit of about 6,5 ℓ capacity was constructed and extensively tested at a private swimming pool during December 1985. Tests were conducted using alum and calcium hypochlorite solutions of about 2,5% concentration as well as tap water. After satisfactory results were obtained, it was decided to construct a larger unit with a capacity of approximately 40 ℓ . The dimensions of this unit is shown schematically in Figure 2.

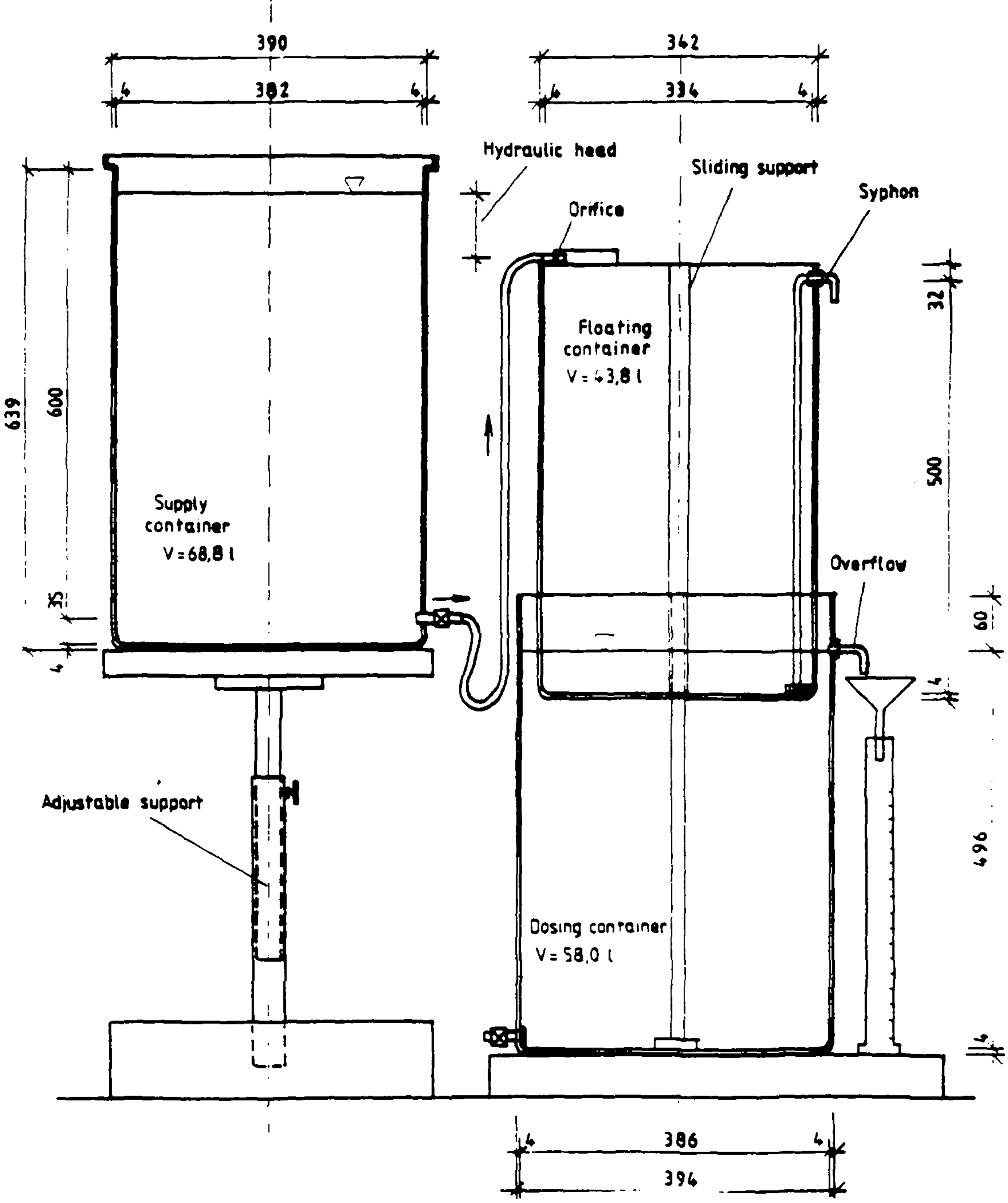

FIG. 2. PROTOTYPE CHEMICAL DOSER

The unit was constructed from polyethylene cylindrical containers which were commercially available. The dimensions of these containers as listed below were subject to commercial availability and theoretically suited for a dosing liquid density of 1,25. It was nevertheless quite suitable to confirm the validity of the basic formulae.

The physical parameters of the prototype doser were as follows:

D_1	=	internal diameter of supply container	38,2 cm
D_2	=	internal diameter of floating container	33,4 cm
D_3	=	internal diameter of dosing container	38,6 cm
t	=	wall thickness	0,4 cm
H_1	=	working depth of water in supply container	60,0 cm
V_1	=	working volume of supply container	68,8 ℓ
H_2	=	internal depth of floating container	50,0 cm
v_2	=	volume of floating container	43,8 ℓ
$h_{2(2)}$	=	submerged depth of floating container into dosing container at start of dosing cycle	6,0 cm
H_3	=	level of overflow in dosing container	49,6 cm
V_3	=	total volume of dosing container up to overflow	58,0 ℓ
D_2	=	external diameter of floating container	34,2 cm
$V_{3(3)}$	=	residual volume	14,0 ℓ

Several runs were made using tap water as both the working and dosing fluids at a high dosage rate and the drop of the water level in the supply container ΔH_1 and the drop of the reference level of the floting container ΔH_2 were measured over a period of time. A ratio $(\Delta H_1 : \Delta H_2)$ equal 0,78 was confirmed which was in close agreement with the calculated value from the basic formulae, i.e.

$$\frac{D_2^2}{D_1^2} \times \frac{\rho l}{\rho w} = \frac{(34,2)^2}{(38,2)^2} \times \frac{1}{1} = 0,80$$

Using water as the dosing liquid ($\rho w = 1$) an increase in hydraulic head with time was therefore induced as anticipated. The hydraulic head would theoretically remain constant for a dosing liquid of density 1,25 for the dimensions of the containers as selected for this particular prototype unit. This was experimentally confirmed by selecting ferric chloride as dosing liquid and adjusting its density to 1,25.

For several weeks the doser was run on tap water to calibrate different orifice plates. Four sizes were tested: 0,5; 1,0; 1,5 and 2,0 mm in diameter. The dosing rates were measured for each plate, setting different initial hydraulic heads in the range from 40 to 700 mm. The results are presented in Figure 3. This shows the dosing rate versus the initial hydraulic head for the various sized orifice plates, plotted on log-log paper. The thick lines are fitted to the experimental points. The thin lines represent intermediate orifice diameters and were calculated from the equation:

$$q = \mu A \sqrt{2 g h}$$

where q = dosing rate (discharge through orifice) (m^3/h)

A = area of orifice (m^2)

μ = coefficient of discharge

h = hydraulic head (m)

The coefficient of discharge was calculated using experimental data for the selected orifice diameters. The chart presented in Figure 3 can be used for selection of an approximate hydraulic head and orifice diameter for a required dosing rate.

DESIGN CONSIDERATIONS AND STEPS

The accuracy of the dosing unit depends on the correct sizing of the individual tanks in order to maintain a constant hydraulic head during a complete dosing cycle. For practical reasons, it is recommended that the dosing cycle be 24 h but this can of course be varied for particular requirements. This means that, once a day, the supply container has to be refilled with water, the floating container emptied, and the dosing container refilled with fresh chemical solution.

A longer dosing cycle of 48 hours for instance will double the volumes of the containers which could cause operational problems such as requiring more than one person to raise or lower the supply container to change the initial hydraulic head. There is practically no limitation in dosing highly concentrated chemical solutions.

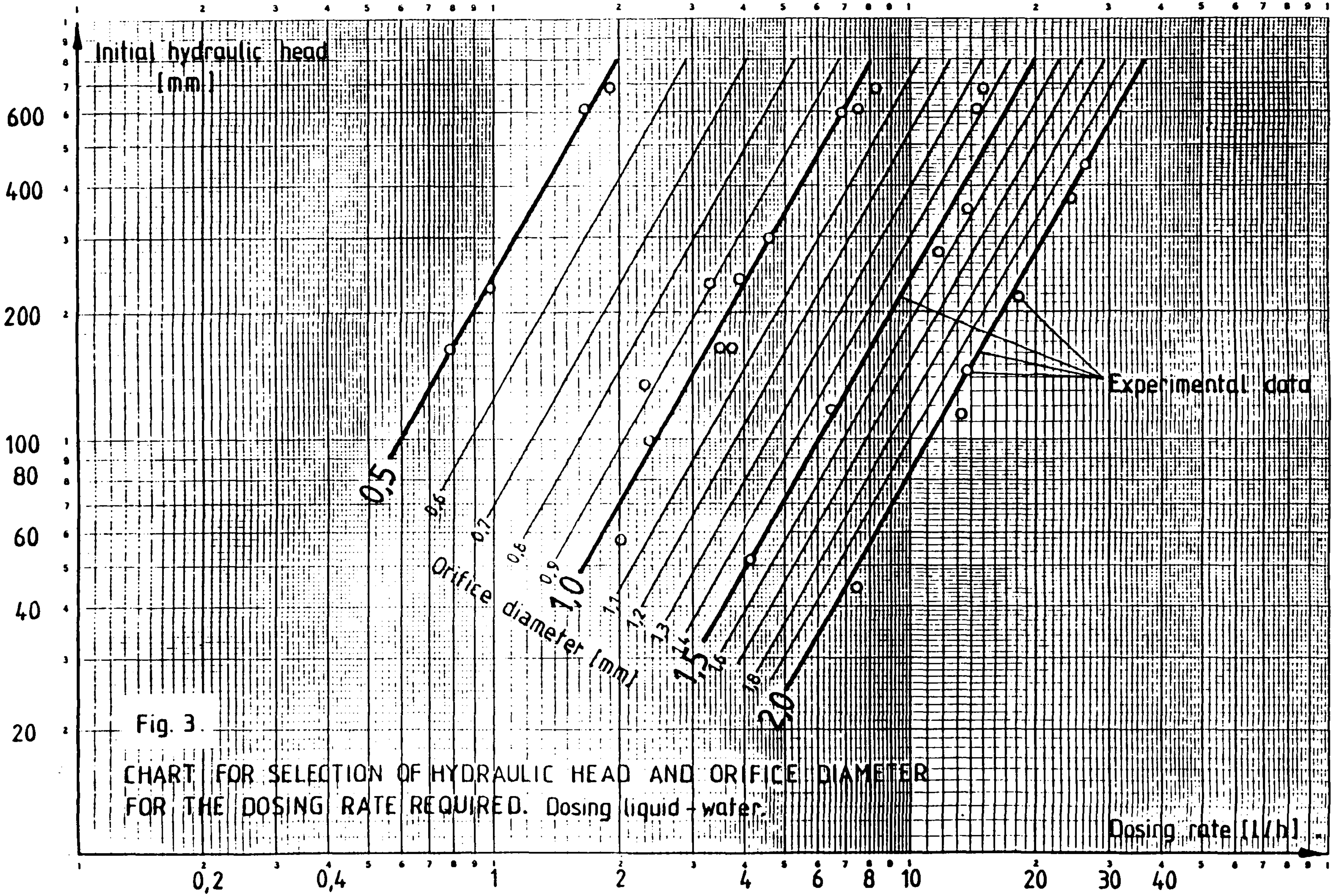

Fig. 3.

CHART FOR SELECTION OF HYDRAULIC HEAD AND ORIFICE DIAMETER FOR THE DOSING RATE REQUIRED. Dosing liquid - water.

The chemical solution which may be corrosive remains in contact with the external surface-area of the floating container only and by selection of suitable materials of construction for floating and dosing containers, corrosive liquids can be readily handled. The advantage of using concentrated chemicals is that for a given dosing requirement, the size of the unit is minimised.

For design purposes the following parameters need to be specified:

- Q = Daily water flow (m^3/d)
- d = dosing requirement (mg/ℓ)
- c = concentration of dosing solution (g/ℓ)
- T = dosing period (cycle) (h), recommended 24 hours
- ρl = specific gravity of chemical solution
- ρm = specific gravity of material of construction of floating container
- R = ratio of internal diameter of dosing container to its working depth
- f = clearance between dosing and floating containers (cm)
- t = wall thickness of floating container (cm)

The design steps include the following calculations:

1. Working volume of dosing liquid to be displaced during a dosing cycle of T hours:

$$V_3(_2) = \frac{Q.d}{c} \times 1000 \quad (cm^3)$$

2. Internal diameter of dosing container:

$$D_3 = \left(\frac{Qd \times 1000}{c} \times \frac{4}{\pi R}\right)^{1/3} \quad (cm)$$

3. Internal diameter of floating container:

$$D_2 = D_3 - 2(f + t) \ (cm)$$

4. Internal depth of floating container:

$$H_2 = V_3(_2) \times \frac{4\rho l}{\pi \times D_2^2} \quad (cm)$$

5. Initial volume of dosing liquid displaced by empty floating container:

$$V_3(_1) = \frac{\rho m}{\rho l} \frac{\pi}{4} [(4D_2t + 4t^2)H_2 + [2D_2 + 2t)^2 \times 2t)] \ (\ell)$$

6. **Equivalent depth** of displacement in dosing container by empty floating **container:**

$$h_3(_1) = \frac{V_3(_1) \times 4}{\pi D_3^2} \quad (cm)$$

7. Internal volume of floating container:

$$V_2 = \frac{\pi}{4} D_2^2 \times H_2 \quad (\ell)$$

8. Submerged depth of floating container into dosing container at start of dosing cycle:

$$h_2(_2) = V_3(_1) \times \frac{4}{\pi} \times \frac{1}{(D_2 + 2t)^2} \quad (cm)$$

9. Level of overflow in dosing container:

$$H_3 = [\frac{V_3(_2) \times 4}{\pi(D_2 + 2t)^2}] + h_2(_2) \quad (cm)$$

10. Total volume of dosing container up to overflow:

$$V_3 = \frac{\pi}{4} D_3^2 \times H_3$$

11. Residual volume of dosing liquid after completion of a dosing cycle:

$$V_3(_3) = V_3 - [V_3(_1) + V_3(_2)] \quad (\ell)$$

12. Equivalent level in dosing container:

$$h_3(_3) = V_3(_3) \times \frac{4}{\pi D_3^2} \quad (cm)$$

13. Internal diameter of supply container:

$$D_1 = [\rho 1 \times (D_2 + 2t)^2]^{1/2} \quad (cm)$$

14. Working depth of water in supply container:

$$H_1 = V_2 \times \frac{4}{\pi D_1^2}$$

These laboriuos stepwise calculations for design purposes can obviously be simplified by computer programmes.

DESIGN EXAMPLES

It is convenient to use a programmable calculator for computing design parameters relating to different concentrations of dosing solution, dosing requirements and flows. A simple programme has been written for the Texas Instruments Tl 59 programmable calculator and a print-out of the results of some design examples for alum and ferric chloride dosing have been included in the Addendum.

These examples are relevant to several existing small-scale water treatment plants where future field testing of the dosing unit is envisaged. The daily flows vary between 100 and 1200 kℓ with dosing rates between 12 and 100 mg/ℓ. For the highest capacity example (Q = 1200 kℓ/d) the dimensions of the tanks (diameters and depths) are typically of the order 50 cm which gives some perspective of size of unit with respect to capacity of plant.

DISCUSSIONS AND CONCLUSIONS

The constant head chemical doser has been tested in the laboratory and for all practical purposes found to be reliable, simple to operate and with good accuracy. Arrangements are under way to conduct field testing of the unit in order to assess its suitability under practical conditions.

It is expected that this device will find some useful application in rural and developing areas where clarification and disinfection of water supplies are problematic.

A further development in progress is to adapt the unit for automatic shut-off and for different levels of dosage requirements. In this regard the chemical removal of phosphates in small-scale sewage treatment plants offers a potential application.

ACKNOWLEDGEMENTS

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DESIGN EXAMPLES

	Alum		Ferric chloride			
Q - daily flow [m^3/d]	100.	100.	480.	720.	1200.	Q
d - dosing requirement [mg/l]	100.	30.	12.	30.	50.	D
c - concentration of dosing solution [g/l]	314.4	625.	625.	625.	625.	C
T - dosing period [h]	24.	24.	24.	24.	24.	T
S_1 - specific gravity of a "c" solution [g/l]	1.177	1.45	1.45	1.45	1.45	SG1
S_m - SG. of material of construction	0.95	0.95	0.95	0.95	0.95	SGM
R - ratio of D_3 to $h_{3(3)}$	1.	1.	1.	1.	1.	R
f - clearance between dosing and floating contain. [cm]	1.	1.	1.	1.	1.	F
t - wall thickness [cm]	0.5	0.5	0.5	0.5	0.5	T'
V_1 - working volume of supply container [l]	37.43638677	6.96	13.3632	50.112	139.2	V1
V_2 - internal volume of floating cont. [l]	37.43638677	6.96	13.3632	50.112	139.2	V2
V_3 - total volume of dosing cont. up to overflow [l]	38.7730546	6.98002048	12.41578351	41.7583523	109.7392375	V3
$V_{3(1)}$ - initial volume of dosing liquid displaced [l]	2.581673184	0.736449709	1.110463734	2.60112093	5.072523685	V3,1
$V_{3(2)}$ - working volume of dosing liquid displaced during T hours [l]	31.80661578	4.8	9.216	34.56	96.	V3,2
$V_{3(3)}$ - residual volume of dosing liquid after T hours [l]	4.384765642	1.443570771	2.089319772	4.597231368	8.666713772	V3,3
D_1 - internal diameter of supply container [cm]	35.06631035	19.60748016	24.9549637	40.10372169	57.35175395	
D_2 - internal diameter of floating cont. [cm]	31.34070397	15.28312599	19.72396935	32.30432812	46.62803927	
D_2+2t - external diameter of floating cont. [cm]	32.34070397	16.28312599	20.72396935	33.30432812	47.62803927	
D_3 - internal diameter of dosing cont. [cm]	34.34070397	18.28312599	22.72396935	35.30432812	49.62803927	
H_1 - working depth of water in supply cont. [cm]	38.71940217	23.05025794	27.32163606	39.6718542	53.88351837	
H_2 - internal depth of floating cont. [cm]	48.52734706	37.93979427	43.73528378	61.14070315	81.51828734	
$h_{2(s)}$ - submerged depth of floating cont. into dosing cont. at start [cm]	3.142768881	3.536532448	3.292066624	2.985859093	2.847139824	
H_3 - level of overflow in dosing cont. [cm]	41.86217105	26.58679033	30.61370268	42.65771329	56.73065819	
$h_{3(1)}$ - initial depth of displacement in dosing cont. [cm]	2.78735956	2.805125586	2.738079847	2.657141979	2.622285465	
$h_{3(2)}$ - equivalent depth of $V_{3(2)}$ in dosing cont. [cm]	34.34070397	18.28312599	22.72396935	35.30432812	49.62803927	
$h_{3(3)}$ - equivalent level in dosing cont. [cm]	4.734107518	5.498538809	5.15165348	4.696243191	4.480333452	
t - wall thickness of floating cont. [cm]	0.5	0.5	0.5	0.5	0.5	
f - clearance between dosing and floating cont. [cm]	1.	1.	1.	1.	1.	
W_2 - empty mass of floating cont. [kg]	3.036629337	1.067852078	1.610172415	3.771625348	7.355159343	
A - internal area of the dosing container [cm^2]	4631.037239	1312.685807	2027.81474	4894.584013	9671.951724	A