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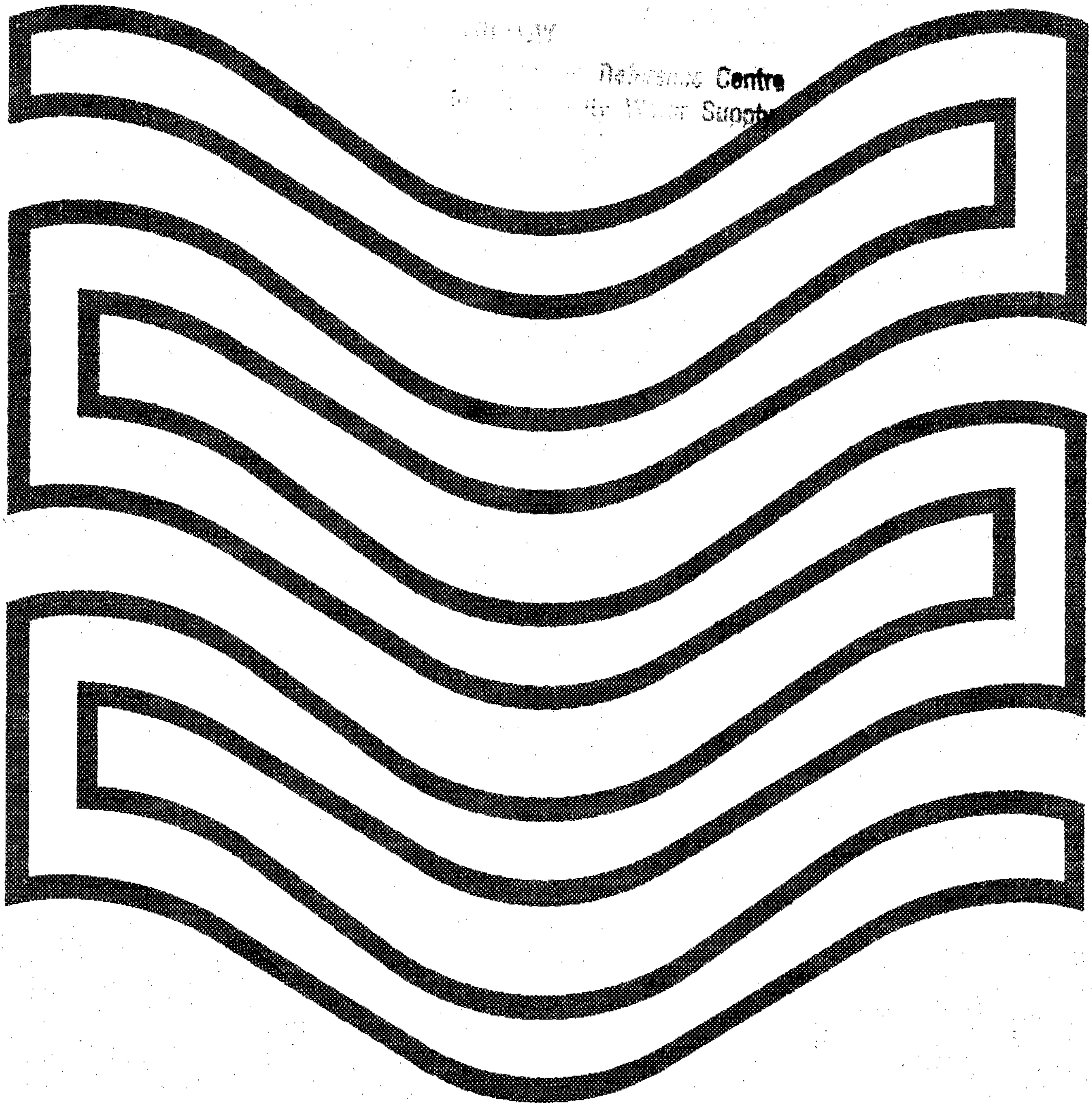
the suitability of iodine and iodine compounds as disinfectants for small water supplies



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WORLD HEALTH ORGANIZATION
INTERNATIONAL REFERENCE CENTRE FOR COMMUNITY WATER SUPPLY

TECHNICAL PAPER NO. 2

The suitability of iodine and iodine compounds as disinfectants for small water supplies.

by

B.C.J. Zoeteman

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C O N T E N T S

SUMMARY

Under poorly controlled circumstances, as present in village tanks that support the water supply of small communities, the low solubility of iodine, its good germicidal capability and its relatively chemical inertness make it a suitable water disinfectant. As compared with chlorine iodine shows the advantage of the ease of handling, longer application under unsupervised conditions, wider pH range, and less susceptibility to interference from ammonia and organic substances in the water to be dosed. However, in concentrations to be applied in polluted waters, with a high initial iodine demand, physiologically toxic levels of iodine will be present. For this reason iodine disinfection should be limited to emergency use and only to those emergency situations where chlorine compounds are giving too many problems e.g. by clogging of the dosing device. Now the risks of toxic effects, that have been found due to polonged exposure and that are even than very infrequent and transistory, are very minor compared with the risks of fatal enteric disease.

A diffusion dosing unit has been developed using a cellulose type of membrane to control the dosing rate. Testing of this device by the Central Public Health Engineering Research Institute, at Nagpur, India, showed that the membrane unit was too delicate for practical application. A less delicate dosing unit with direct contact of disinfectant and water probably with a less accurate dosing rate, has been proposed.

1. INTRODUCTION

Iodine, in addition to its many medical uses, has long been recognized as an effective agent for disinfection of drinking water.

Black et al. (1) defined an ideal water disinfectant as a material that is chemically weak and unable to participate in reactions with organic materials, but, at the same time, possessing strong disinfecting properties. Iodine is in many respects such an ideal disinfectant.

The practical application of elemental iodine as a water disinfectant was described for the first time by Vergnoux (2) in 1915, who recommended it as a rapid disinfection method for troops under field conditions. It was not until 1953 that Chang and Morris (3) published their basic studies on disinfection with iodine, which showed its effectiveness against bacteria, viruses and cysts. These studies were primarily responsible for the adoption of iodine by the military for the disinfection of canteen water in the field.
In 1959 Black, Lackey and Lackey (4) published the first study of iodine's effectiveness for disinfection of swimming pool water. Since that time the use of iodine in swimming pool disinfection has become more and more popular. Studies on other possible uses of iodine like the disinfection of public water supplies, have been reported by Black et al. (1) in 1965 concerning water systems in prisons and in 1968 (5) concerning the effect of iodine on taste and odour development after the iodinated water has passed the water distribution system of a city.

It is well known that iodine is a scarce and expensive chemical and that it has a great therapeutical value. From this point of view its waste on a big scale can usually not be justified and a careful evaluation of the advantages of iodine as compared with the cheaper and physiological inert chlorine is necessary.
The dangers involved with long-term ingestion of iodine or iodine compounds will be discussed in this report to determine a safe dosing limit for the drinking water supply. Subsequently, the results of the practical research will be reported and recommendations as to the practicability of iodine disinfection and further studies will be given.

2. BIBLIOGRAPHY

Introduction

The devitalizing properties of iodine and chlorine or substances that release the active halogen compounds will be reviewed briefly from the existing literature. Special attention is paid to the influence of physical and chemical factors on the bactericidal, cysticidal and viricidal efficiency of both halogens, which are of great importance to their suitability as disinfectants under field conditions.

Physical properties

Some general physical properties of both halogens are listed in table 2.1.

Halogen	Mol. weight	Melting Point (°C)	Boiling Point (°C)	Vapour Pressure at 30°C (mm Hg)	Solubility in water at (mg/l)
Chlorine	35.45	-101.0	-34.6	7600	5700
Iodine	126.90	113.5	184.4	0.4	400

Table 2.1. General physical properties of chlorine and iodine.

Figures 2.1. and 2.2. (page 8.) show the influence of temperature on vapour pressure (6) and solubility (7).
At temperatures, that have to be expected in natural waters, iodine is in the solid state. It has a relativelylow solubility in water and as a solid material a relative high vapour pressure. These properties give iodine an advantage over chlorine gas as far as dosing of the disinfectant under primitive conditions is concerned. Especially a dosing system based on the high volatility of solid iodine seems to be attractive. The low solubility of iodine in water can be helpful in preventing overdosing under poorly controlled circumstances.

Disinfection mechanism

The devitalizing action of chlorine is due to its oxidizing capacity that is developed after hydrolysis and the subsequent liberation of nascent oxygen in the cell (8) as represented by the following equations:

$$Cl_2 + H_2O \rightleftharpoons HClO + H^+ + Cl^-$$

$$HClO \rightleftharpoons H^+ + Cl^- + O$$

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Figure 2.1.

INFLUENCE OF TEMPERATURE ON THE VAPOUR PRESSURE OF CHLORINE AND IODINE

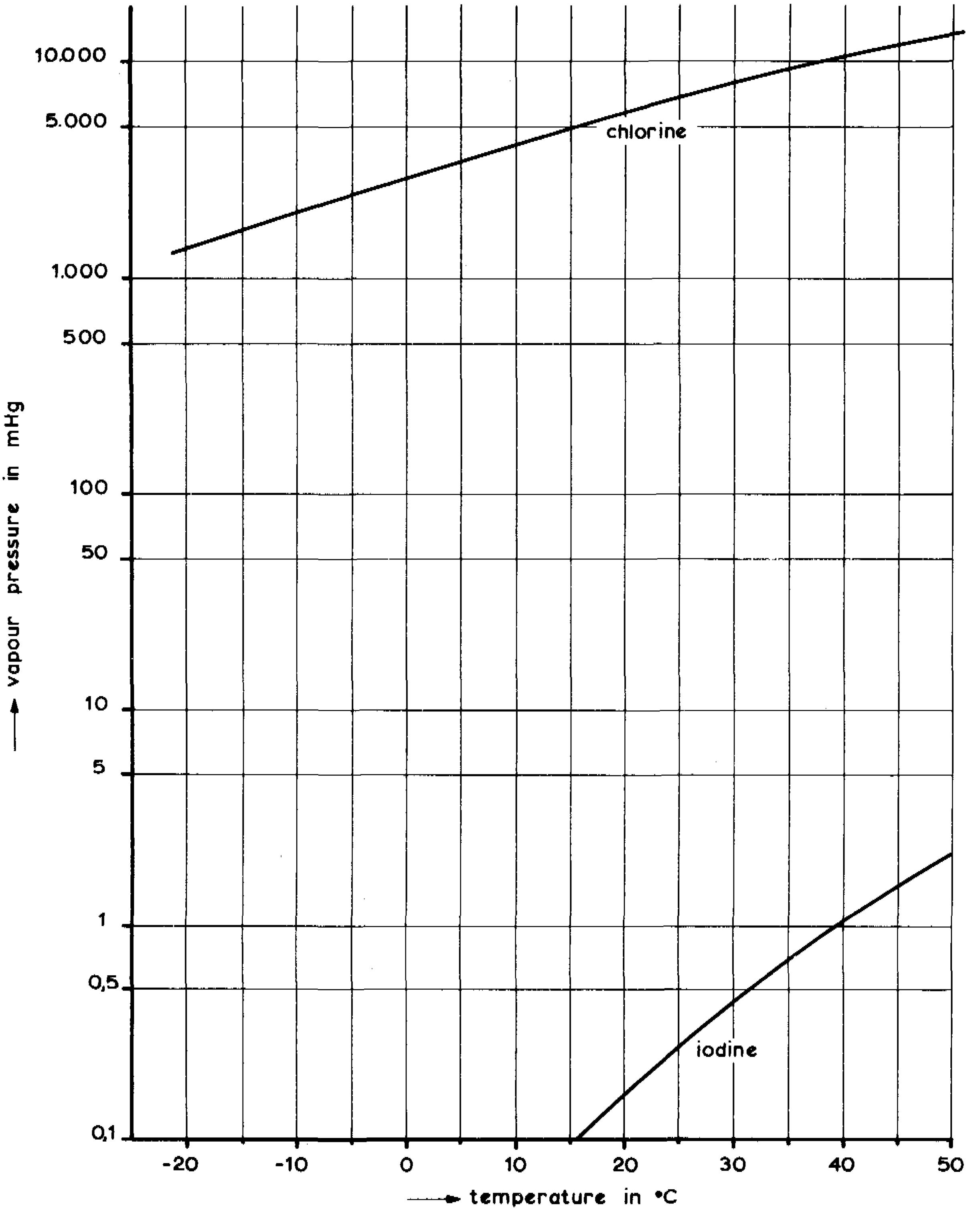

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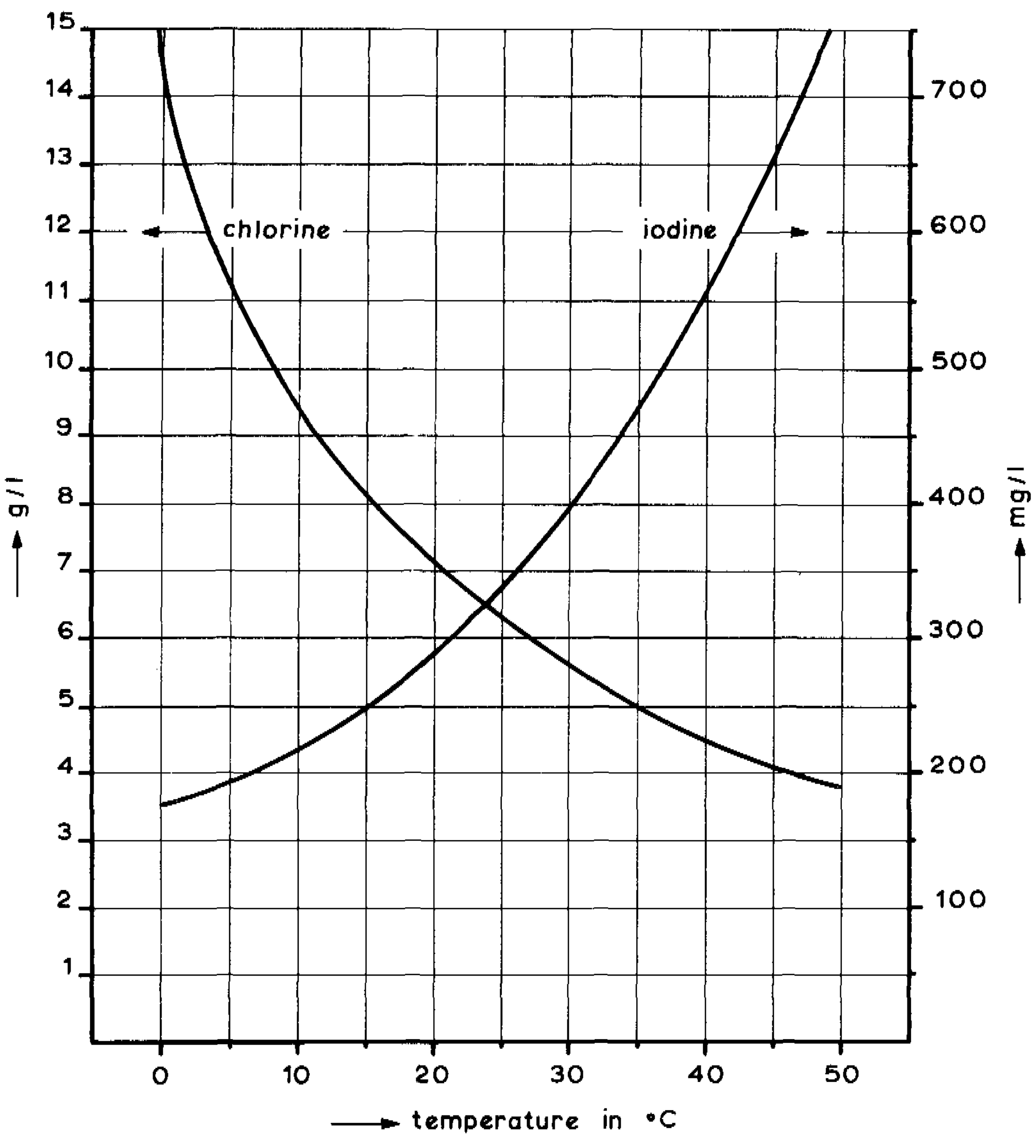
Figure 2.2.

SOLUBILITY IN WATER OF CHLORINE AND IODINE AS A FUNCTION OF TEMPERATURE



At pH values normally occurring in drinking water the hypochlorous acid (HClO) is partly dissociated:

$$HClO \rightleftharpoons H^+ + ClO^-$$

Disinfection by iodine is supposed to be caused by direct iodination of vital cell substances such as proteins and nucleic acids (9). After hydrolysis of elemental iodine several ions can be formed as illustrated by the following reaction equations:

$$I_2 + H_2O \rightleftharpoons HIO + H^+ + I^-$$

$$HIO \rightleftharpoons H^+ + IO^-$$

$$3\ HIO + 2OH^- \rightleftharpoons H^+ + IO_3^- + 2H_2O + 2I^-$$

$$I_2 + I^- \rightleftharpoons I_3^-$$

All halogen-containing ions possess very little or no disinfecting capability (10). For disinfection only chlorine and hypochlorous acid or iodine and hypoiodous acid have to be considered. The explanation for this is the penetration mechanism of the disinfectant through the cellwall into the inner of the cell, before the chemical oxidation or substitution reaction with vital substances can take place. Because all ions are hydrated the cellwall will retard the diffusion of these ions into the cells. This diffusion is much less retarded in the case of electrically neutral molecules like hypochlorous acid and hypoiodous acid.
Berg, Chang and Harris (9) found that the reaction between only one molecule of iodine and one site in a virus appears to be necessary for devitalization of the virus. The high resistance of different viruses against disinfection depends very much upon their ability of clumping. The effect of clumping is that part of the available vital sites are protected against the action of the disinfectant. From these facts, Berg, Chang and Harris conclude that the resistance gradient of devitalization of viruses with iodine is probably directly related to the number, reactivity and availability of vital sites in the virus.
The greater sensitivity of bacteria for devitalization may be attributed to the greater number of vital sites present in these larger organisms. The greater resistance of spores and cysts may be attributable to the slow diffusion of the disinfectant through the wall of these organisms, resulting in lower effective concentrations in the areas where devitalization takes place.

Germicidal action

The bactericidal, cysticidal and viricidal action of both disinfectants will now be considered.

- Bactericidal action

  The fundamental bactericidal activity of iodine in water is about as great as that of hypochlorous acid (11) (table 2.2.)

Halogen	pH	Free residual concentration for a reduction factor of 10^7 in p.p.m.
Cl_2	6	2
I_2	8	2 - 5

Table 2.2. Bactericidal activity of chlorine and iodine for E.coli and a contact time of 10 minutes in Cambridge (Mass.) tap water (3).

Chang and Morris (3) showed that in tap water all pathogenic bacteria are killed within 5 minutes by 7 ppm iodine at 25°C. Escherichia coli, Salmonella typhosa, Sh. dysenteriae, Sal. schötmuelleri were shown to be a little more resistant than Vibrio cholera.
Black et al. (5) found that E.coli is killed four times more rapidly than Strep.faecalis, while Staph. aureus is slightly more resistant to iodine and chlorine than Esch.coli, but much less resistant than Strep. faecalis.

A study on the bactericidal efficiency of chlorine, bromine and iodine using tap water from the East Bay Municipal District at Berkeley, California was published by Beckwith and Moser (12). Some of their results with E.coli are listed in table 2.3.

Halogen	% killed at initial dose of		
	0,25 ppm	0,5 ppm	1,0 ppm
Cl_2	14,3	28,6	39,2
Br_2	97,4	100,0	100,0
I_2	68,8	99,6	100,0

Table 2.3. Devitalization of E.coli by chlorine and iodine after a contact time of 10 minutes in tap water at 20°C.

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Figure 2.3.

DESTRUCTION OF BACTERIA, CYSTS AND VIRUSES BY I_2 AND HOI AT 18°C

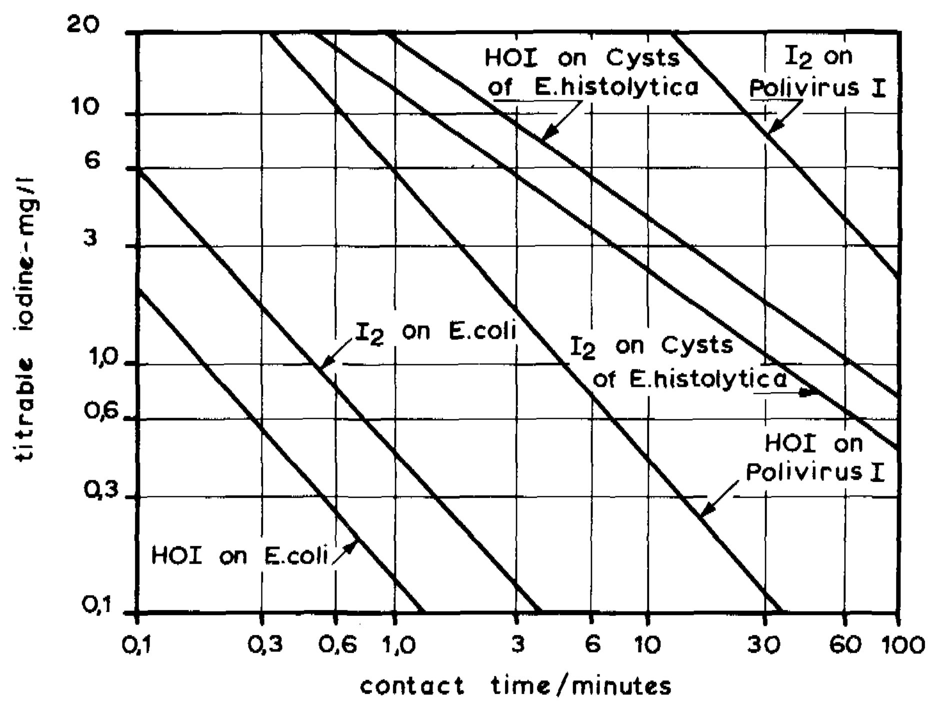

Table 2.3. clearly shows the greater disinfecting efficiency of iodine compared with chlorine under practical conditions. The low efficiency of chlorine in this case might be due to a rapid formation of combined chlorine, that possesses approximately a 10 times lower bactericidal capability than free chlorine (13) (14).

- Cysticidal action

The quantitative relationship between the cysticidal residual halogen concentration (C) and contact time (t) can be expressed by the equation (3):

$$C^n . t = k$$

where C is in p.p.m. and t in minutes ; n is the cysticidal residual halogen concentration coefficient and k is a constant that depends on the temperature and the initial cyst concentration.
In the case of cysts of Entamoeba histolytica n = 1,5 for iodine and n = 1,0 for chlorine (15). Thus, concentration level is relatively more important and time of contact less important in the destruction of cysts by iodine as compared with hypochlorous acid. This is just the reverse of the behavior of Bacillus metiens spores in relation to these two germicides, even though the required concentrations of killing agent are about the same for both types of organisms (16) (17).

As table 2.4. shows it may be stated that there are no significant differences between the cysticidal efficiency of chlorine and iodine.

Halogen	Cysticidal residual halogen in p.p.m.
Cl_2	7,5 (13)
I_2	6,6 (10)

Table 2.4. Cysticidal residual concentrations for Entamoeba histolytica at pH = 8 and 25°C (calculated from the literature for a contact time of 5 minutes).

- Viricidal action

The viricidal ability of chlorine and iodine is a very important factor in the comparison of these disinfectants because some viruses belong to the most resistant micro-organisms known. Berg and associates (see 18) showed in comparative tests at 25°C that 99 % of Coxsackie A9 virus was destroyed in 52 minutes by 1,0 mg/l of iodine, while the same iodine

concentration destroyed 99 % of E.coli in only 0.03 minute.
From a survey of the literature, Kabler et al (18) conclude that Theiler's virus is more resistant to the action of free chlorine than Coxsackie A2 virus, which is more resistant than poliovirus type 1. Adenovirus type 3 shows about the same resistance as Escherichia coli.

In table 2.5. the viricidal action of iodine is compared with the action of free and combined chlorine.

Halogen	Contact time in minutes	
Chlorine	0,5	(19)
Combined chlorine	100	(20)
Iodine	50	(9)

Table 2.5. Approximate contact times necessary for 99 % kill of poliovirus type 1 at 5 p.p.m. halogen concentration, 15^{o}C and pH = 7.

Although iodine is an effective viricide, table 2.5. shows that its effectiveness is considerably less than that of free chlorine and slightly better than that of combined chlorine.

From the above it can be concluded that the activity of iodine is about the same as the activity of chlorine in destroying pathogenic bacteria and cysts. However, the viricidal activity of iodine is considerably less than for chlorine. Thus, the use of iodine as a water disinfectant requires greater residuals and longer contact than in the case of hypochlorous acid.

Effects of physical and chemical factors on disinfection

The effectiveness of chlorine and iodine as disinfectants can be influenced by pH, temperature and the presence of water contaminants like ammonia and organic materials causing turbidity and colour in the water.

- Effect of pH

  pH has an important influence on hydrolysis and dissociation of chlorine, iodine and their compounds. Some data on the influence of pH are compiled in table 2.6. These data have been calculated by Black et al. (1) using data from Chang (7) and Wattie and Butterfield (21).

pH	Content of residual in %					
	I_2	HIO	IO^-	Cl_2	HClO	ClO^-
5	99	1	0	0	99.5	0.5
6	90	10	0	0	96.5	3.5
7	52	48	0	0	72.5	27.5
8	12	88	0.005	0	21.5	78.5

Table 2.6. Effect of pH on hydrolysis of iodine and chlorine.

At higher pH the disinfection ability of chlorine decreases rapidly, because of the increasing presence of the hypochlorite-ion. At pH = 8.0 only 21.5 % of the chlorine is present as the germicidally active hypochlorous acid while at this pH all the iodine is present as active iodine or hypoiodous acid.

Studies of Chang (7) and Black et al (1) (5) showed that the presence of the bactericidally inactive tri-iodide and iodate ions can be neglected for the pH-range common in drinking water practice.

On the other hand a difference was found (7) (5) between the disinfection properties of I_2 and HOI as shown in figure 2.3.

In view of these facts it is clear that pH has only a small influence on disinfection efficiency of iodine under drinking water conditions while at increasing pH the disinfection efficiency of chlorine rapidly decreases.

- Effect of temperature
  Higher temperatures increase the germicidal efficiency of chlorine as well as iodine (3) (7) (9). The cysticidal action of iodine is less dependent on temperature than this action of hypochlorous acid. This is just the reverse in the case of spores of B.metiens.
  Because not only the velocity of the devitalizing reaction is increased at higher temperatures but also other chemical reactions as well as the volatility it is very difficult to evaluate the over-all influence of increased temperature under field conditions.

- Effect of water contaminants
  The high reduction-oxidation potential of hypochlorous acid (table 2.7.) has the disadvantage that part of the added chlorine is involved in chemical reactions that has nothing to do with disinfection, like oxidation of organic substances originating from the vegetation.

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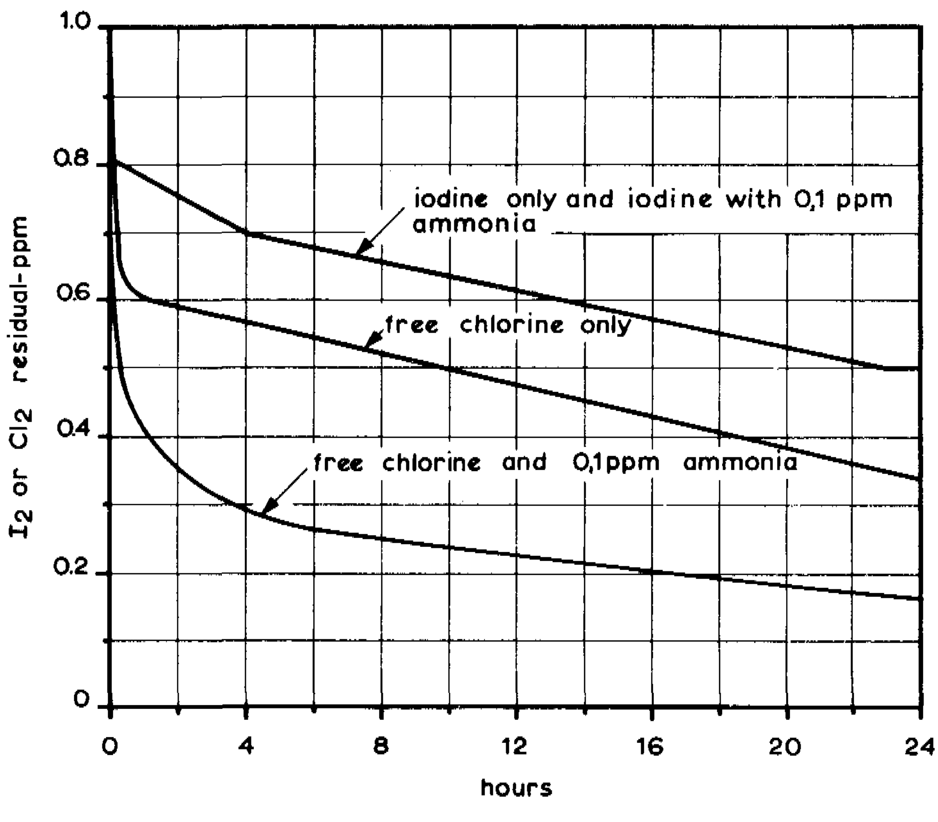
Figure 2.4.

HALOGEN DEMAND OF WATER AFTER ADDITION OF AMMONIA AT 24°C. AND pH = 7,5



Equilibrium - equation	Normal redox potential (Volt)
$HClO + H^+ + 2e \rightleftharpoons Cl^- + H_2O$	1.49
$HIO + H^+ + 2e \rightleftharpoons I^- + H_2O$	0.99
$I_2 + 2e \rightleftharpoons 2I^-$	0.536

Table 2.7. Redox potentials

One of the most frequently occurring reactions is that between chlorine and ammonia resulting in the product chloramine that possesses a much lower disinfecting capacity than hypochlorous acid. Black et al (1) studied this phenomenon extensively. Some of their results are illustrated in figure 2.4., from which it is clear that in the pressure of ammonia in the water iodine disinfection will be more reliable than chlorine disinfection.

Chang and Morris (3) found that most clays have no effect on disinfection efficiency of iodine, with the exception of the very fine loess.

High turbidity as well as high organic colour of the water due to the presence of humic acids, makes it necessary to add more disinfectant to the water or to apply longer contact times. This effect is more pronounced for chlorine than in the case of iodine disinfection.

Summary

In a technically well-controlled water supply system the use of chlorine or chlorine compounds for water disinfection should be far preferred over the use of iodine or iodine releasing substances. This is because of the low cost and high germicidal efficiency of chlorine, the ease of preparation of stock solutions and the possibilities for controlling pH and presence of water contaminants that influence the residual free chlorine concentration. The presence of skilled personnel is very important for the safe handling of poisonous chlorine gas or for the appropriate storage of chlorine compounds that slowly decompose, especially under humid and hot circumstances.
However, under primitive conditions iodine has some advantages over chlorine. Based on its volatility and low solubility a simple dosing device might be constructed, while changes in pH and the presence of ammonia and organic substances do influence the disinfection efficiency considerably less than in the case of chlorine.

A very important factor in the use of iodine as a disinfectant for drinking water is the health hazard involved with prolonged use of this halogen. In the next chapter more details on the physiological effects of iodine will be presented.

3. PHYSIOLOGICAL EFFECTS OF LONG-TERM INGESTION OF IODINE

Iodine is widely used in the medical therapy of endemic goitre.
The immediate cause of simple goitre is failure of the thyroid gland to obtain a supply of iodine sufficient to maintain its normal structure and function (22). The disease occurs endemically in several regions of the world where natural sources of iodine are inadequate. The relative importance of goitre declined dramatically after the widespread supplementation of human and animal foods with inorganic iodine.
It is estimated that 0,1 - 0,2 mg of iodine per day will prevent goitre in man (23) (24). Matovinović and Ramalingaswami (25) are of the opinion that the therapeutic dose need not be higher than 0,2 - 0,3 mg per day. Paradoxically, iodine can cause goitre too, when ingested in large amounts. Complications of iodine therapy of goitre due to excessive administration of the chemical are rare. However, in the course of the treatment with iodine the following can occur (25):

- iodism
- Jod-Basedow
- iodine thyroiditis
- enlargement of the goitre with or without hypothyroidism

Iodism is an allergic reaction of over-sensitive people to iodine when the therapeutic dose of iodine is much larger than the daily requirement. The allergic reaction can be either of an acute or of a chronic nature. Acute iodism is manifested by angioneurotic symptoms, from urticaria to haemorrhagic exudates. Chronic iodism is more common than the acute form, the main symptoms being chronic rhinitis, enlargement of the salivary glands and various acneiform exanthemas.

Jod - Basedow is the development of hyperthyroidism in the course of goitre therapy when the therapeutic dose is considerably larger than the daily requirement. As a result of prolonged nutritional deficiency of iodine hyperactive nodules can develop in a goitre. It is these nodules that secrete almost all the hormone, the remaining thyroid tissue being practically inactive. Given a larger supply of iodine, the nodules can produce excess of thyroid hormone, thus inducing Jod-Basedow. Thus iodine does not cause, but conditions the development of the disease. Stanbury and his collea ues (26) reported a case of a woman with endemic goitre who developed Jod-Basedow after the administration of 1,5 mg of iodine per day. The symptons of Jod-Basedow usually disappear spontaneously several weeks after the administration of excessive iodine has been discontinued.

<u>Iodine thyroiditis</u> appears sometimes at the beginning of iodine therapy. It is an enlargement of the goitre which may be painful. The complication can occur about the seventh day of therapy if large doses are administered. After iodine therapy has been discontinued the goitre decreases spontaneously. Iodine thyroiditis is a transitory harmless phenomenon.

<u>Enlargement of the goitre, with or without hypo-thyroidism</u> occurs after the administration of massive doses of iodine (50 - 500 mg or more per day) for the treatment of bronchial asthma, arteriosclerosis e.o. This iodine induced goitre arises because in some people and some animals (27) iodine in large doses inhibits the release of thyroid hormone into the blood-stream. The shortage of thyroid hormone in the blood leads to a compensatory increase in the secretion of thyrotropin which produces enlargement of the thyroid. This type of goitre disappears spontaneously after the administration of iodine has been discontinued and the concentration of iodine in the blood has decreased.

All the above complications of iodine therapy of goitre are very infrequent. Among 1000 adults, most of them with large nodular goitres, who received large doses of iodine (5 - 15 mg per day) under careful and frequent control, only one patient developed iodine thyroiditis and one Jod-Basedow (25).
Lowenstein (28) concludes that the benefits of iodine to the people in an endemic goitre area far outweigh the risk of an occasional toxic effect. Freund, Thomas et al (29) (30) studied the general health and thyroid function of healthy people during consumption of iodinated water at a level of 1 p.p.m. over a three-year's period. None of the test persons developed clear clinical evidence of hyperthyroidism or hypothyroidism. At concentrations of 5 mg/l the iodide increment resulted in a decrease to 2 % of the normal RAI uptakes (24hr Radioactive Iodine Uptake by the thyroid gland) and to PBI values (Protein Bound Iodine) that were greater than the normal 4 to 8 microgram/100 ml of serum.

From these facts it is clear that a prolonged administration of several milligrams of iodine per day can have adverse effects to individuals with a history of thyroid disease. The health hazards for healthy individuals seems to be low, although no data are available on the physiological effect of prolonged use over many years, especially in children.

In compliance with a statement of the American Water Works Association (31) it can be concluded that the possible toxic effects of iodine for susceptible individuals and the still unknown health hazards existing during prolonged administration of several milligrams of iodine, do not justify uses other than its emergency use as a potable-water disinfectant.

4. PRACTICAL RESEARCH ON SIMPLE DOSING METHODS

4.1. Introduction

The development of a simple and reliable dosing unit, ready for emergency uses, is very urgent problem, because of the tremendous health hazards in tropical developing countries involved with an inferior quality of the drinking water during and after flood or earthquake disasters and in areas adjacent to territories of war.

As outlined in the preceding chapters chlorine disinfection will be much more attractive than iodine disinfection in situations where skilled labour is available. Emergency disinfection at water works should preferably be accomplished by dosing chlorine solution. Emergency disinfection at locations where the use of handpumps is common or the population is used to work with storage vessels some type of bleaching powder dosing (e.g. erosion feeding using HTH tablets (32) or chlorine solution dosing by dripfeed devices can be recommended.

Finally, the application of iodine or iodine compounds as disinfectants should be limited to emergency disinfection of the primitive water supply to small communities. As examples may be mentioned open wells or multipurpose village "tanks" (33).
Of the latter hundreds of thousands are in use, especially in Africa and Asia. They vary as to size and may be natural in origin or artificially constructed. They are all polluted, highly dangerous and potential spreaders of epidemics and harbourers of pathogenic bacteria, viruses and parasites. Especially under disaster conditions they account for an incalculable number of cases of sickness and death, particularly of children.

Under these conditions there will neither be time nor possibilities to control the level of the iodine concentration in the water. The input of the relative persistent iodine must be controlled, as far as the desired concentration is concerned, by adding one or more dosing units (e.g. from a helicopter) in proportion to the estimated water content of the well, the cistern built on the verge of tank or river, or a similar draw-off point, and the number of people served by it. The basic principle of the dosing unit has to make an optimal use of the advantages of the low solubility in water of iodine to overcome dangers involved with the poorly controlled circumstances. This is the reason why the iodine releasing compounds called "iodophors" are not suitable for this purpose. Iodophors are complexes of iodine with various surface activa agents which "carry" iodine and give it an excellent solubility in contact with water.

The variations of the iodine concentration in the village tank should be limited between a germicidal effective lowest and a toxicological acceptable highest level. According to the results of tests concerning simple chlorine dosing units (34) (35) the principles of the disinfection by adding solid iodine must be based on diffusion feeding.
First a mathematical approach will be given on the variability of the iodine concentrations that can be expected in water of a tank using any kind of diffusion feeding. Then the results of a simple method of iodine will be discussed.

4.2. Calculation of the iodine feed rate

Assuming a village tank with a water content of V m^3 and an average water withdrawal of P m^3/hour over a period of t hours, it is possible to calculate the necessary iodine feed rate d, presuming the existence of an initial iodine level of C_{t_o} g/m^3 at the start of the daily water withdrawal in the early morning.

After the first hour of water withdrawal in the morning the iodine concentration will be approximately:

$$\frac{(V-P)\ C_{t_o} + d}{V} = C_{t_1} \qquad \text{(formula 1)}$$

After n hours the iodine concentration (C_{t_n}) will be:

$$C_{t_n} = \left[\frac{V-P}{V}\right]^n C_{t_o} + \frac{d}{V} \sum_{n=o}^{n=n-1} \left[\frac{V-C}{V}\right]^n \qquad \text{(formula 2)}$$

At any time during the night period, when no water is consumed, the iodine concentration will be represented by:

$$C_T = C_{t_{end}} + T.\frac{d}{V} \qquad \text{(formula 3)}$$

where:

C_T = iodine concentration after T hours of production stop

$C_{t_{end}}$ = iodine concentration at the moment water production is stopped after t_{end} hours of withdrawal.

If ideal conditions are strived after, the iodine concentration at the end of the night period should be equal to the iodine concentration at the start of the withdrawal at the preceding day, which means that:

$$C_{t_o} = C_{T_{end}} \quad \text{(formula 4)}$$

Substitution of formula 4 in formula 2 and 3 results in the equation for the feed rate d:

$$d = V.C_{t_o} \frac{\left[1 - \frac{V-P}{V}\right]^{t_{end}}}{T_{end} + \sum_{n=o}^{n=t_{end}-1} \left[\frac{V-P}{V}\right]^{n}} \quad \text{(formula 5)}$$

In the specific case that $V=6m^3$, $P=0,5\ m^3/h$, $C_t=1.75$ p.p.m. I_2 and $t_{end}=12$ hours the needed iodine feed rate shows to be 0.34 gram I_2/hour. Using this feed rate the iodine concentration in the given example will range between 1.09 p.p.m. and 1.75 p.p.m. assuming no iodine losses by evaporation and chemical reactions. In practice a higher feed rate will be necessary to maintain these concentrations depending on water temperature and water contamination. Although iodine concentration will increase considerably when no water is withdrawn from the tank over a period of several days it is suggested to supply each dosing unit with sufficient iodine for disinfection over a period of several weeks. This is because consumption of overdosed water will be prevented by the brown colour and the taste that becomes noticeable at levels above 2 to 5 p.p.m.. Moreover, evaporation of the iodine will render the overdosed water palatable again after some time.

In the case of this example a total quantity of approximately 150 grams of iodine would be sufficient for disinfection over a period of 2 weeks. Chemical costs of a device would be U.S.$ 1 cts/m^3 at an iodine price of U.S. $ 7,-/kg.

4.3. A simple iodine dosing unit

Three possible methods of diffusion feeding of iodine have been considered and various devices have been subjected both to laboratory and to field experiments under working conditions:

- Feeding by plastic tubes supplied with a variable open slit in the tubewall
- Feeding by porous cartridges
- Feeding through iodine pervious membranes

Experiments with plastic tubes with a variable open slit in the tubewall and filled with solid iodine showed that it was impossible to

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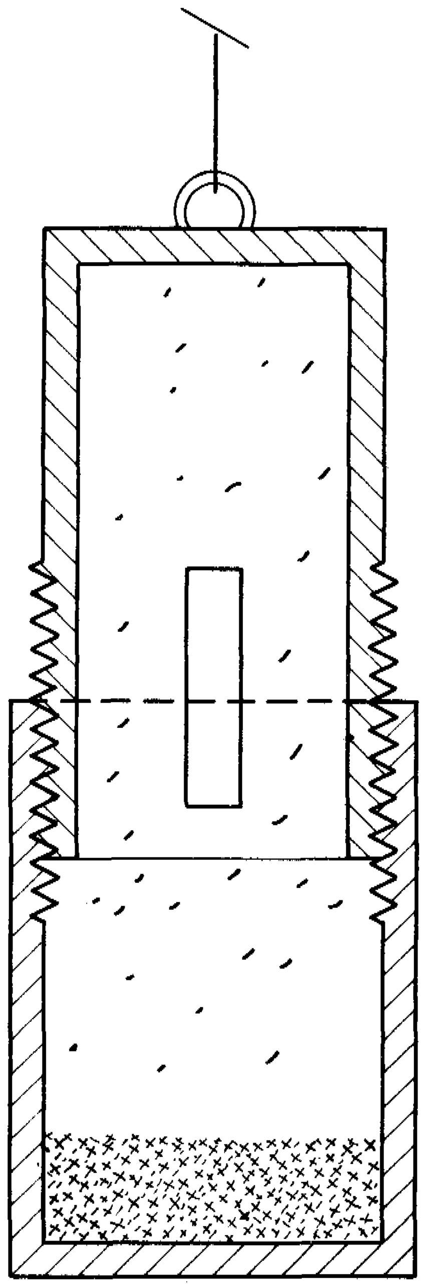
Figure 4.1.

PLASTIC TUBE WITH VARIABLE SLIT



control the iodine feeding at a fixed constant rate. The dissolving iodine forms a solution of high specific density and is concentrated at the bottom of the feeding tube (see figure 4.1.). The dosing rate decreases after a short time and soon becomes too low for practical application.
Also feeding by porous cartridges has many problems. A high feeding rate exists as long as the innerside, which is filled with iodine crystals, remains dry. Now iodine vapour penetrates the cartridge wall and dissolves in the water. However, water too is penetrating the cartridge wall and as soon as it renders the iodine wet the diffusion rate decreases very rapidly to impractical low values.
For these reasons iodine dosing by iodine pervious membranes was studied more in detail.

Membrane materials used for iodine feeding must be watertight, chemically as inert as possible and the pores in the membranes must be large enough to allow the passage of iodine molecules.
In principle a controlled iodine feed rate is obtainable by varying the membrane surface area that separates the iodine from the drinking water. Four suitable membrane materials, that are commercially available, have been tested. The specifications are summarized in table 4.1.

Name	Pore diameter (Å)	Weight (g/m^2)	Application
Visking 1)	26	> 40	dialysis tubing
Cellophan PT400 2)	> 100	40	packing material
Cellophan PT300 2)	> 100	30	packing material
Cuprophan PT150 2)	> 200	15	artificial kidney material

Table 4.1. Specification of four tested commercial available cellulose type membranes.
1) from South Holland Instruments, The Hague, The Netherlands
2) from ENKA, Arnhem, The Netherlands.

As can be seen from figure 4.2.a* the feeding rate can be increased considerably by using air filled iodine containing units instead of water filled units. Under the condition of air filled units the iodine molecules will pass the membrane as non hydrated molecules, which results in higher dosing rates.

* Iodine was determined by a spectrophotometric method (1) (36).

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Figure 4.2.

Figure a Iodine feed rate as function of membrane surface area and application of dry or dissolved iodine in spherical shaped membrane bags.

The influence of application of dry iodine or iodine solution

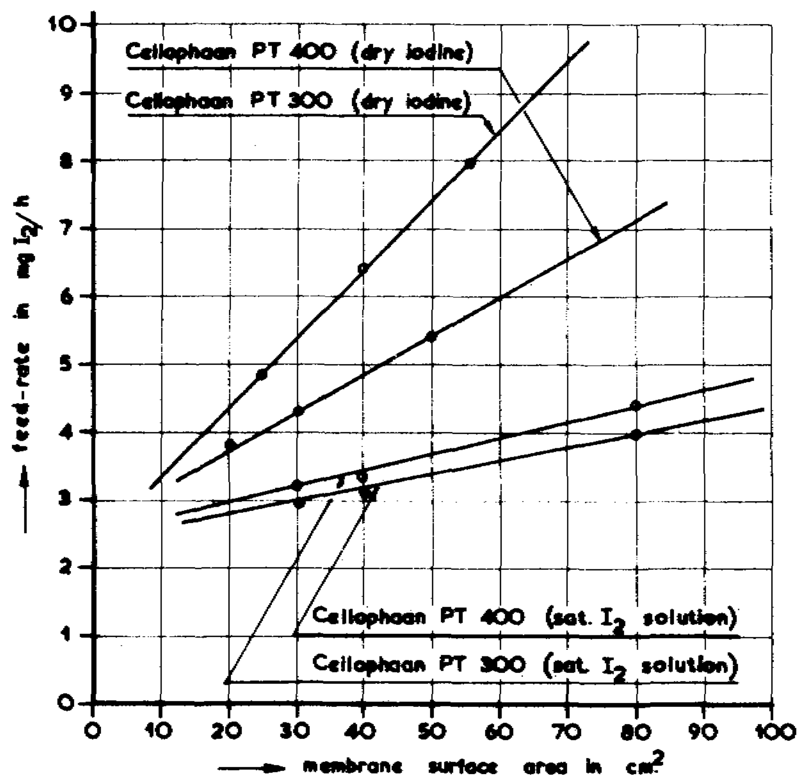

Figure b Iodine feed rate as function of membrane surface area and membrane material applying dry iodine in spherical bags.

The influence of different membrane materials

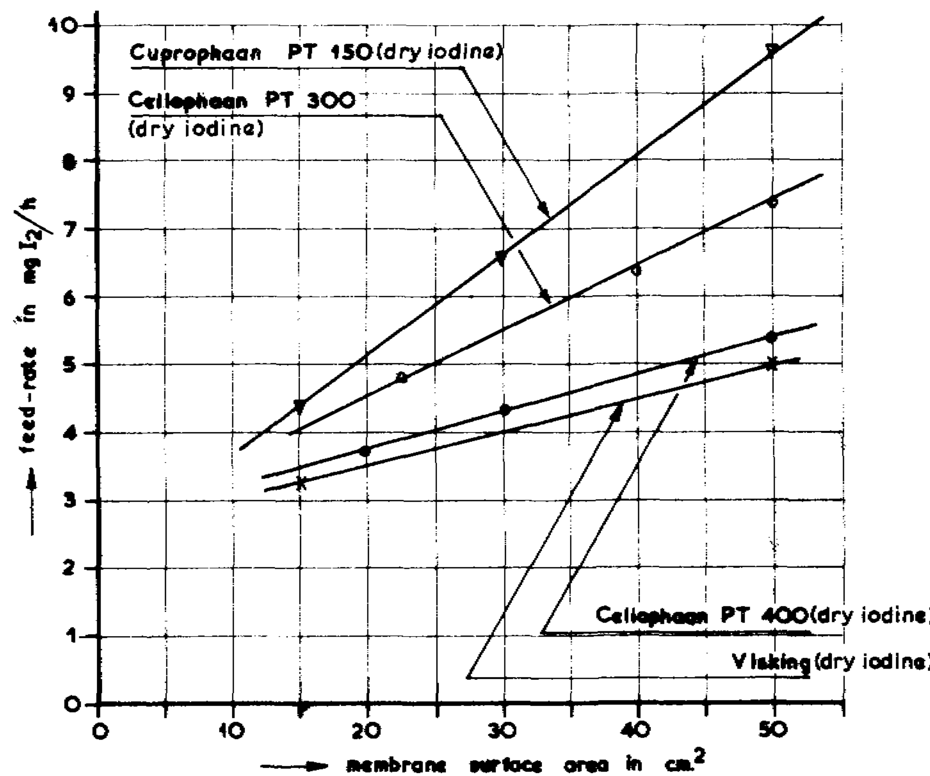

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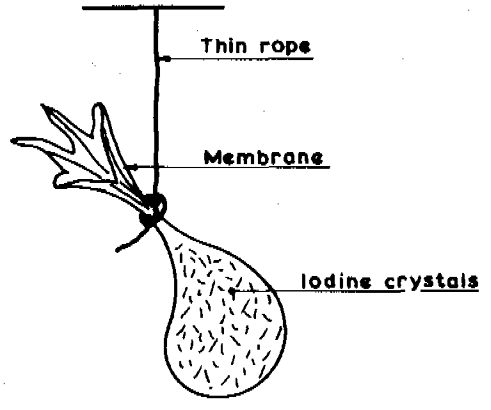
Figure 4.3.

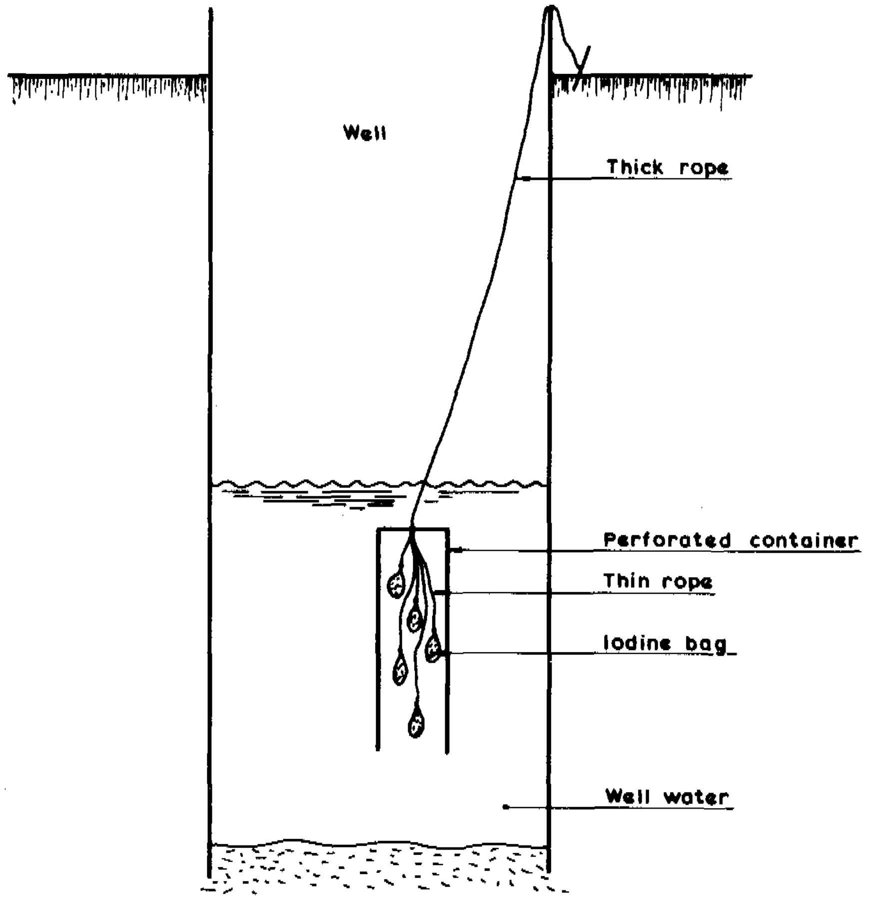
IODINE BAG

A



DOSING IN WELL (SCHEMATICAL)

B



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The results of experiments with the different membrane types using the air-iodine units are summarized in figure 4.2.b. It is clear that Cuprophan PT150 is the most attractive cellulose material.
Using flat membranes instead of spherical ones the feed rate could be increased to about 5 mg I_2/hour per 10 cm^2 of Cuprophan PT150 membrane at 20^oC. This means that in the village tank, used as example before, a dosing unit containing 700 cm^2 of membrane surface could be applied, which is of reasonable size.
During the development of a dosing equipment based on iodine vapour diffusion through a cellulose type membrane, several difficulties were met.
Firstly, it was tried to find an adhesive for the membrane that was watertight because the membranes could not be heatsealed. This search for a suitable adhesive, although many types were tested, remained unsuccesful.
Another possibility for a watertight closure of the membrane unit is to use a mechanical locking system.
Finally two prototypes of the dosing unit, one consisting of membrane bags closed by a fine rope (figure 4.3.) and one consisting of a plastic container with two membrane sheets that form an iodine chamber (figure 4.4.), were developed and tested under field conditions by the Central Public Health Engineering Research Institute in Nagpur, India.
Under the tropical circumstances in India the feed rate of the unit was found to be about two times higher than in the laboratory tests in The Netherlands. A much more important factor was that the membrane (Cuprophan PT150) was getting softened and it lost its strength after a slimy bacterial growth of non-spore forming Bacillus was formed after some days. In 20 days the membrane lost its strength completely and water accumulated in the units.
Another disappointing phenomenon was the high iodine demand (about 60 p.p.m. in 24 hours) of the test water that must have originated from the high organic contamination and the high temperature.

From these results it is evident that the membrane feeding unit is too delicate for practical purposes and that evaporation of iodine from the water in combination with a high initial iodine demand play a very important role in the practice of direct village tank disinfection.

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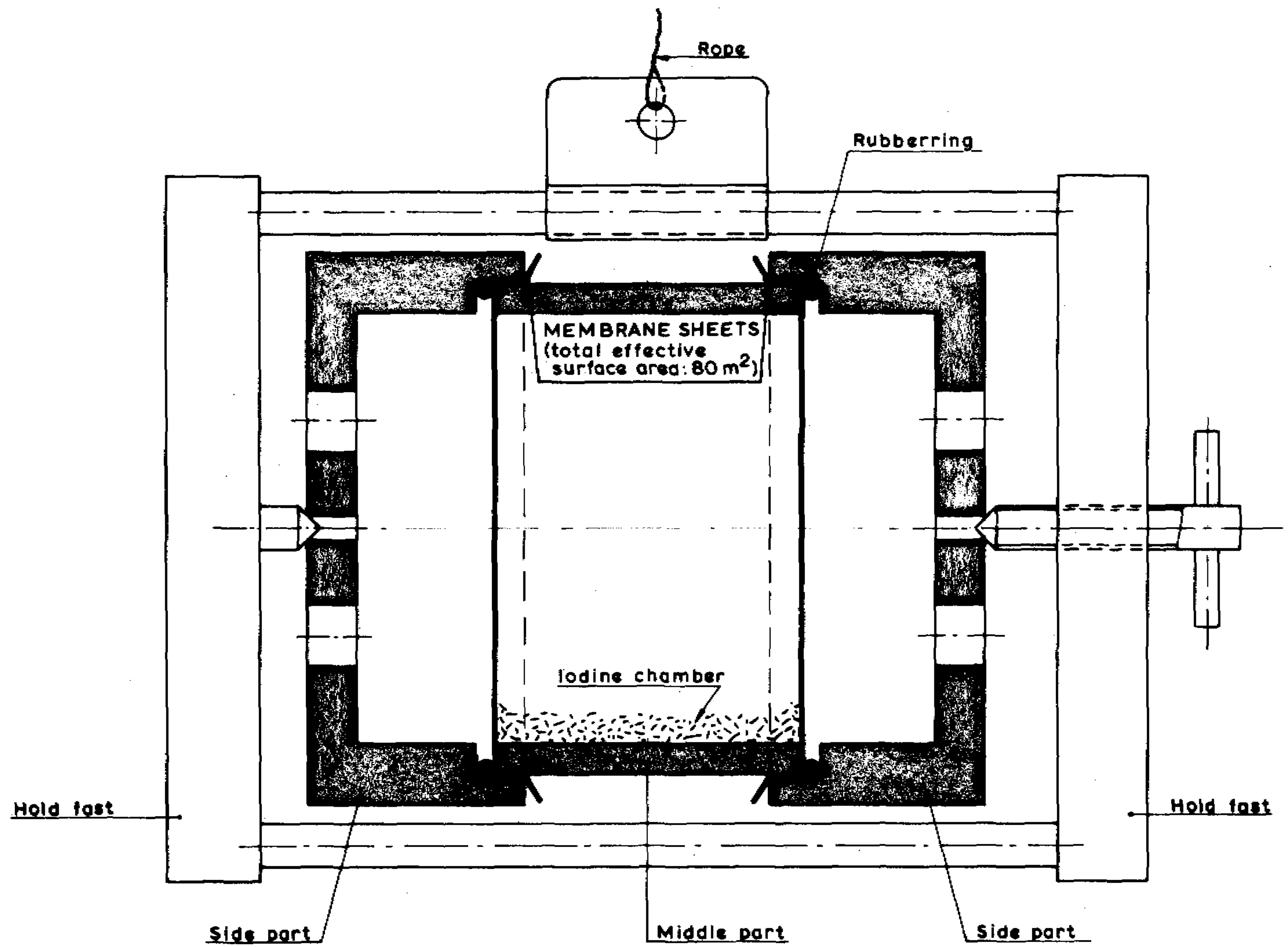
Figure 4.4.

DOSING DEVICE WITH MEMBRANE SHEETS



SCALE 1:1

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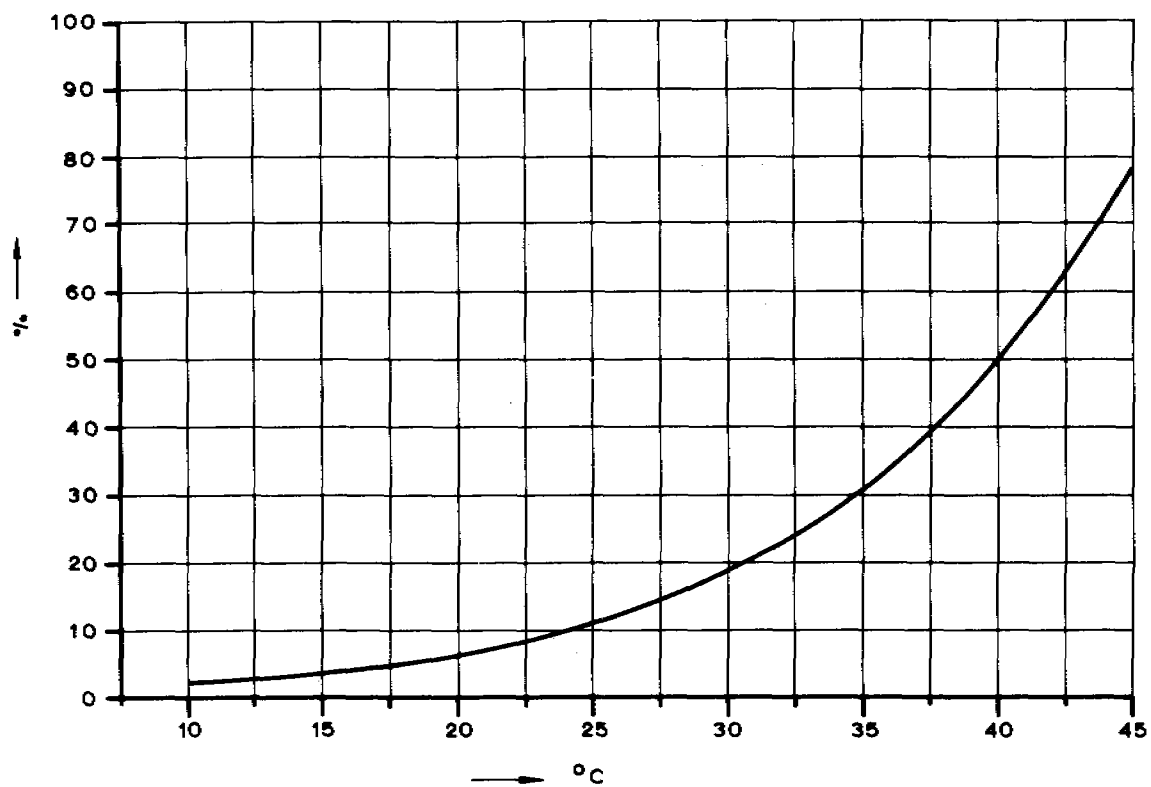
Figure 5.1.

EVAPORATION OF IODINE FROM A WATER SOLUTION OF 25 p.p.m. AS A FUNCTION OF THE TEMPERATURE AFTER 24 HOURS



5. RECOMMENDATIONS

In spite of the attractive properties of iodine for water disinfection under primitive conditions it has some important disadvantages that became apparant during the studies by CPHERI, Nagpur, India. To overcome the high iodine demand of contaminated water, that has to be expected in a village tank, high iodine doses are necessary to build up a satisfactory iodine level for disinfection. At these high iodide levels (10 to 50 or more mg/l) the toxic physiological properties of iodine will have much more pronounced effects than at the advisable level of 1-2 p.p.m. Under these circumstances the property of iodine not to react with ammonia to combined halogen-nitrogen compounds should be qualified as a disadvantage because in the case of chlorine dosing the chloramines would take care of an important part of the disinfection.
So, in the polluted water of a village tank chlorine disinfection should still be preferred over iodine disinfection. The high volatility of iodine in aqueous solution (see figure 5.1.) leads to the same conclusion.

The disinfection of polluted water in a village tank by chlorine or chlorine compounds however, is difficult because of the high solubility or the problem of formation of calciumcarbonate deposits on the dosing unit. Thus in emergency times the disadvantages of iodine disinfection might be accepted for a short period as long as no alternative compound, e.g. one that slowly releases chlorine, is available. In this case high dose rates will be necessary to establish a microbiologically safe water quality.

Under circumstances where water quality is not too bad, temperature does not rise above 30^{o}C and the iodine demand is smaller than 10 p.p.m., application of emergency iodine disinfection might be suitable (e.g. collecting well of "within-tank" filtered water (33)).

May be other membrane materials can be found that are less susceptible to softening and degradation.

Figure 5.2. represents schematically a possible dosing unit for a solid material that slowly releases its germicidally active compound.

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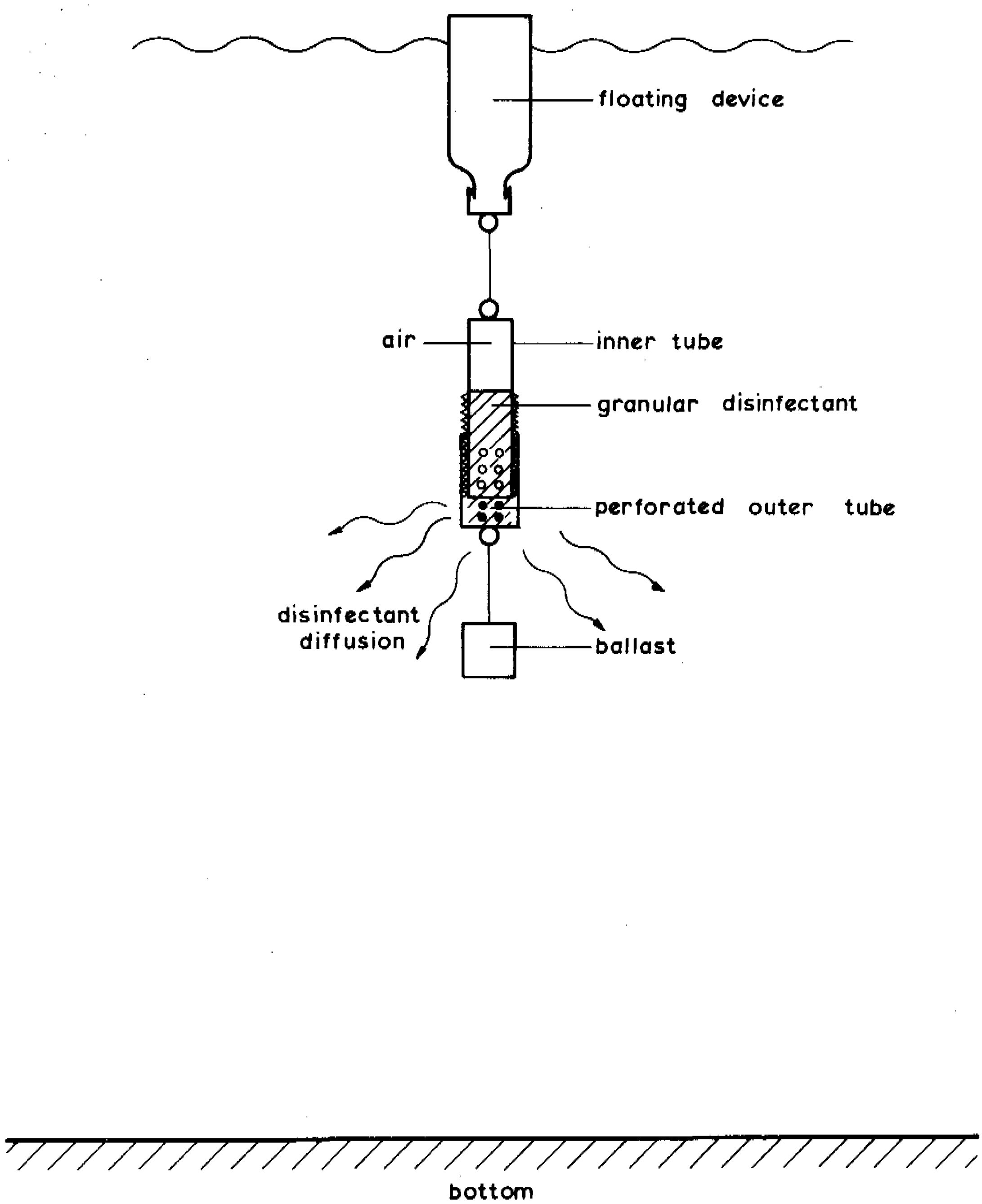
Figure 5.2.

POSSIBLE DOSING DEVICE FOR DIRECT APPLICATION IN VILLAGE TANK



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