Bull. Org. mond. Santé } 1973, **49**, 451-460
Bull. Wld Hlth Org. }

Removal of viruses from sewage, effluents, and waters

1. A review

GERALD BERG [1]

All sewage and water treatment processes remove or destroy viruses. Some treatment methods are better than others, but none is likely to remove all of the viruses present in sewage or in raw water. Primary settling of solids probably removes a great many of the viruses in sewage because viruses are largely associated with the solids. Long storage of effluents or water is destructive to viruses. Activated sludge is the best biological method for removing viruses from sewage. Trickling filters and oxidation ponds are erratic, the latter probably because of short-circuiting. Coagulation with metal ions is the most effective single treatment method for removing viruses from sewage and from raw waters, according to laboratory studies at least. Lime is the best coagulant for these purposes in the rapidly virucidal high pH range. Polyelectrolytes also can sediment viruses. Rapid filtration through clean sand does not remove viruses, but filtration of coagulated effluents does, probably because the layering floc itself adsorbs viruses. Clays and carbon adsorb viruses to some extent, but the process is not efficient. Ultimately, disinfection should help to produce virus-free waters for drinking and virus-free effluents for discharge into waters with which man may come into contact. Because disinfection is not a simple matter, disinfectants must be selected according to need. Effluents and waters containing solids can probably be disinfected only by heat or by penetrating radiation, waters discharged into streams should not be disinfected with anything that will injure or kill aquatic life (unless the toxic products can be neutralized), and drinking-waters should carry a disinfecting residue.

As the world's populations expand and concentrate more and more in centralized communities, the disposal of urban sewage and the viruses within it presents problems of increasing magnitude.

Biological and chemical treatment processes, and settling and storage alone, remove vast quantities of viruses from sewage, but there are always residual viruses that are a hazard to all who come into contact with the waters containing them. Disinfection of effluents and disposal of sludges require special caveats. Raw water sources, contaminated increasingly by pollutants, become more refractory to treatment and more difficult to be made potable.

In developing countries, the problem is often more acute, and the limited resources available for dealing with it may require novel and individual solutions.

The literature of the past reveals that there is yet much to be learned and much to be done, and unfortunately some to be redone.

[1] Chief, Biological Methods Branch, Methods Development and Quality Assurance Research Laboratory, National Environmental Research Center, Environmental Protection Agency, Cincinnati, Ohio, USA.

TREATMENT PROCESSES

Primary settling

Primary settling, long said to remove few of the viruses from sewage, may be much more effective than was thought, even in a 3-hour detention period.

When poliovirus 1 was added to sewage in 2 experiments, the amounts of the viruses demonstrable in the upper portion of that sewage did not diminish until 3–6 hours later (23). Only one-third to two-thirds of the viruses had settled after 24 hours, although about 75% of the solids had settled. There is, however, no accurate way to assess the amounts of virus that had been imbedded and adsorbed within faecal materials and other solids.

Others have reported that primary treatment did remove viruses, but did not state the detention time and, what is more important, did not relate

temporally the levels of viruses in the incoming sewage (influent) with those in the effluent from the plant (53). Since large variations in the virus load of domestic sewage may occur in any 24-hour period, the temporal relationship of measurements on influents and effluents is critical. Other studies have reported little or no virus removal by primary settling (11, 34, 54, 63, 64, 80). Settling in Imhoff tanks has been reported to produce no virus removal either (4, 15, 53, 54, 80).

Storage

In situations where it is feasible, long storage may be the simplest method for destroying viruses (5), even though the survival of viruses in various waters is determined by the water's quality, which is often indeterminate, and the temperature (1, 2, 21, 56, 71).

Destruction of 99.9% of poliovirus 1 and echovirus 12 in sewage required about 60 days of storage at 10°C and less than 20 days at 30°C. Similar destruction of echovirus 7 took almost twice as long (5, 24). The survival of viruses adsorbed to particulates was not determined in these studies. Thus, the protection afforded to adsorbed viruses on and within solid matter was not assessed.

Trickling filters

Trickling filters appear to remove viruses erratically. In repeated tests, Shuval recovered 16–100% of the amounts of viruses detected in the primary effluents entering the filters (80). Others have also reported poor removal of viruses by trickling filters (4, 15, 73). It may be that viruses passing through filters simply do not make good contact with the adsorptive surfaces and that many viruses are eventually eluted even when they do (7, 8).

Stabilization ponds

The removal of viruses by stabilization ponds is also erratic, even though conditions of pond treatment are normally deleterious to viruses. Ponds allow for long periods of storage, exposing viruses to noxious chemicals, microbial life, adsorptive solids, and ultraviolet light (8). Yet erratic and often poor levels of virus removal are consistently reported, and these cannot be accounted for solely by the lack of careful temporal matching of samples from influents and effluents.

Shuval reported virus removals ranging from 0 to 96% in ponds with a 20-day retention time (80). From an oxidation pond with a 30-day retention time that was fed activated sludge effluent containing a relatively small number of viruses, England et al. recovered viruses from almost 20% of 87 effluent samples (34). Malherbe & Strickland-Cholmley found highly variable virus removals in a pond with a 19-day retention period, but noted short-circuiting, which may account for much of the great variability generally experienced with the removal of viruses by stabilization ponds (64).

Activated sludge

If it is assumed that samples of effluent from the plant represent the same material taken as influent when both samplings are done concurrently, then activated sludge appears to be the best of the biological treatment procedures for removing viruses from sewage.

In field studies, Kelly & Sanderson found little removal of viruses by activated sludge (53). In subsequent laboratory studies, however, they found up to 78% removal of seeded poliovirus 1, but less than 40% removal of seeded coliphage T2 after 4 hours of aeration (54). Aeration appeared to be essential for virus removal, but the mechanical stability of the floc was not. Biological antagonism was also thought to be a factor in removal of the viruses.

With a bench model, continuous-flow, activated sludge unit, Clarke et al. found that more than 90% of seeded poliovirus 1 was removed from the sewage after about 7 hours of retention (23). More than 99% removal of coxsackievirus A9 occurred under similar conditions. They also noted that 75% of seeded virus disappeared within 5 minutes after it was added to raw sewage. Freundlich isotherms prepared from these data strongly supported the role of adsorption in the virus removal process.

In some field studies of our own, there was 70% or less removal of viruses by activated sludge (Berg et al., unpublished observations, 1970). In other studies, large variations were found in the virus levels of sewage demonstrating the importance of temporally controlled sampling if accurate measures of virus removal are to be achieved for any process (Safferman et al., unpublished observations, 1972).

Other demonstrations of virus removal by activated sludge give relatively few quantitative data. Mack et al. reported virus removal by activated sludge that sometimes exceeded 90% (63). Bagdasar'jan & Kazantceva (3) also reported some virus removal, as did Isherwood (49). England et al. noted removals of 76–90% of all three types of poliovirus (vaccine virus) by activated sludge (34), while Pálfi et al. detected no removal by this process (73).

It is not unusual to detect little or no virus removal in activated sludge plants that are not operating well, although the temporal coordination of sampling may also be a factor.

Circulating oxidizing channels

Little research has been done on the removal of viruses from sewage by circulating oxidizing channels, although this method of treatment is now widely used in small villages and in isolated areas.

In one study with an aerated 15-litre laboratory model seeded with sewage and activated sludge, Gončaruk et al. found that more than 90% of seeded echovirus 19 was removed from sewage in 2 days, and more than 90% of coxsackievirus B5 was removed after one day of retention in the system (41).

Adsorbents

Globa et al. reported that polygoskite, bentonite, aglaporite, vermiculite, Permutit, pyrophillite, gypsum, and silica gel adsorbed viruses from water, and may be used for that purpose before coagulation in water purification processes (40).

Chemical coagulation, softening, and pH

Coagulation is probably the single most effective chemical procedure, short of disinfection, for removing viruses from water and wastewater. Coagulation may be effected by a number of metal ions and also by polyelectrolytes. Alum [$Al_2(SO_4)_3$] and lime [$Ca(OH)_2$] are the two most common salts that supply metal ions for this purpose. Salts of iron have also been used effectively.

Alum. Gilcreas & Kelly obtained only 40% removal of a coxsackievirus from a seeded spring water with alum, under conditions that removed 90% of the coliform organisms (39). Alum, however, can efficiently remove viruses from water.

Thorup et al. showed that 10 mg of alum per litre removed only 12% of poliovirus 1 from distilled water containing no turbidity, but removed 79% of the virus when the water contained 50 mg of clay per litre (89). Clay itself is a good virus adsorbent, especially in the presence of salt (16, 89).

Chang et al. found that 25 mg of alum per litre removed 99% of coxsackievirus A2 seeded into river water (17). Good removal of virus was dependent on good floc formation, but was independent of temperature. Good floc formation depended on coagulant concentration. Coliform organisms were removed equally well. Chang postulated that coagulation with alum results in the formation of aggregates of a coagulant–cation–virus complex that settles from solution.

At concentrations of 50 mg per litre, alum removed 94% each of seeded coliphage T4 and phage MS2 from diluted primary effluent (18, 19). In undiluted sewage, virus removals were considerably less efficient, apparently because of interference by organic matter.

The investigators who reported these studies were able to recover viruses from the alum sludge and were concerned about the hazard presented by the disposal of such sludges. Others have also recovered viruses from metal-precipitate sludges and some have expressed similar concern (12, 39, 65).

Brunner & Sproul (12) found that at pH 5, in distilled water and in domestic effluent from an extended aeration plant, alum removed 90% of seeded poliovirus 1 when 24 mg of PO_4^{2-} per litre were precipitated by an equal molar concentration of Al^{3+}, and 98% of the virus was removed when 30 mg of PO_4^{2-} per litre were precipitated, again with an equal molar concentration of Al^{3+}. Better removals were obtainable at pH 6.4 than at pH 5 or 7.3.

Lime. 99–99.9% of poliovirus 1 seeded into primary effluent was removed by precipitation with either 400 or 500 mg of lime per litre (10). Smaller amounts of lime removed less of the virus. The pH of the effluent significantly affected virus removal. At a pH level of 10, little virus destruction occurred, but between pH 10.8 and 11.1 (the latter level was reached when 500 mg per litre of lime were applied), a rapid increase in the rate of virus destruction occurred. The rate at pH 11.1 was sufficient to produce 90–99% destruction of the virus in the 90-min contact of the coagulation process. The virucidal value of high pH in treatment trains was suggested some years ago (6).

Thayer & Sproul (88) reported that 90% inactivation of phage T2 resulted after 90 minutes of contact when sufficient lime was added to distilled water to produce a pH level of 10.5. Lund (62), however, noted viable viruses in precipitates formed with lime at pH levels of 10.5–11. Wentworth et al. (93) reported no inactivation of poliovirus 1 when enough lime was added to maintain a pH of 11.2 for 90 min, but Sproul et al. (85) reported that, when the lime concentration was raised sufficiently to produce a pH of 11.9 in distilled water, 90% inactivation of poliovirus 1 occurred. In distilled water, sodium

hydroxide at pH 11.9 and potassium hydroxide at pH 12.2 also produced 90% inactivation of poliovirus 1 after 90 min of contact.

In water softening, precipitation of calcium carbonate with lime removed 70% of poliovirus 1 when 300 mg of calcium carbonate per litre was sedimented. Almost 99.9% removal of the virus occurred, however, when 300 mg of magnesium hardness per litre was precipitated (88, 93). The magnesium hydroxide formed in the precipitation was believed to have acted as a coagulant (83).

Salts of iron. In a concentration of 25 mg/litre, iron(3+) chloride removed 92–94% of coxsackievirus A2 from the river water into which it had been seeded (17). As with alum, good virus removal was contingent upon good floc formation and was independent of temperature. Used in tandem, alum and iron(3+) chloride removed about 99.9% of the virus.

Manwaring et al. (65) reported that coagulation with iron(3+) chloride removed coliphage MS2 as effectively as alum did from water containing 150 mg of clay per litre. At pH 5, 60 mg of iron(3+) chloride per litre removed 99.7% of the virus from water containing no organic matter, but only 67% of the virus from water containing 200 mg of sewage effluent per litre. Calcium and magnesium ions did not affect virus removal.

Thorup et al. reported that 11.6 mg of iron(3+) sulfate per litre removed only 20% of poliovirus 1 from distilled water containing no turbidity, but 85% of the virus when the water contained 50 mg of clay per litre (89).

Polyelectrolytes. Johnson et al. reported 99.99% removal of poliovirus 1 by a copolymer of 2,5-furandione (" maleic anhydride ") (51). These workers have directed their recent efforts with polyelectrolytes toward adsorbing viruses for detection purposes.

Chaudhuri & Engelbrecht obtained 99.9% removal of coliphage T4 and 99–99.6% removal of coliphage MS2 in deionized water with synthetic cationic polyelectrolytes, but the results were poorer with anionic and nonionic polyelectrolytes (18, 19). Thorup et al. experienced smaller removals of poliovirus 1 and coliphage T2 with cationic polyelectrolytes used as primary coagulants and even poorer results with anionic and nonionic polyelectrolytes (89). These workers found virus removal to be salt-dependent. When sufficient alum or iron(3+) sulfate was used to give good coagulation, the polyelectrolytes did not increase virus removal. Sproul (83) did not believe that the apparent differences between the results reported by Chaudhuri & Engelbrecht (18, 19) and Thorup et al. (89) were real.

Watson & Drewry removed more than 99.9% of seeded coliphage f2 from trickling filter effluent and from synthetic river water with an anionic polyelectrolyte, but found a cationic polyelectrolyte relatively ineffective (91).

Sand filtration

Viruses are not adsorbed by clean sand (Berg et al., unpublished observations, 1970; 69, 77). Yet filtration through sand can remove viruses. Although experimental data in this area are often erratic, slow filtration apparently removes viruses more effectively than rapid filtration (39, 77), and the presence of coagulated floc results in the retention of large amounts of viruses (10, 77). Although clean sand will not adsorb viruses from clean water, viruses will adsorb to organic matter trapped by sand, to floc similarly trapped, and perhaps to other salts bridging to the sand as well (69).

Gilcreas & Kelly found that filtration through sand at about 7.5 litres/min per m^2 removed almost 99% of seeded coxsackievirus A5, although filtration at 75 litres/min removed only about 10% of the virus (39).

Robeck et al. noted a general trend toward better removal of poliovirus 1 with slower filtration rates, although their data were generally erratic (77). At slow sand filter rates (0.6–1.2 litres/min/m^2), removals ranged from 50% to about 98%. At rapid filtration rates (38–76 litres/min/m^2), virus removals ranged from about 10% to 70%.

Drewry & Eliassen found that virus adsorption by soils was affected by pH, with better adsorption at low than at high pH levels, and that adsorption increased at higher cation concentrations (33).

Grigor'eva & Gončaruk seeded septic tank effluent samples with coxsackieviruses A5 and A14 and a coliphage, and passed the seeded samples through medium-grained experimental sand filters and through filtering wells (42). Seeded effluents were fed into the filters daily for 42 days. Viruses were not detected in the filtrates of the experimental filters after the twentieth day of operation. The filtering wells did not perform as well. The authors believed that the buildup of organic matter in the experimental filters was responsible for their performance. Coliform organisms were more efficiently removed by the filters than the viruses, and were not detected after a time when the viruses still persisted.

Carbon adsorption

Cookson (27–30) and Cookson & North (31) have done most of the work published on the removal of viruses from sewage effluents by filtration through activated carbon. These workers reported that only 35% of the tailed coliphage T4 was retained by carbon filters receiving effluents at a rate of 19 litres/min/m^2. Adsorption was maximum at pH 7 and decreased as pH changed from this level, probably because of factors peculiar to the tail structure of the virus. Adsorption was reversible. Cookson's data suggest that adsorption of the virus by carbon is probably mediated through carboxyl groups or lactones on the carbon and amino groups on the virus. Adsorption of this virus in activated carbon columns apparently occurs in a manner consistent with mass transfer theory.

Sproul et al. found that organic matter in a secondary effluent seeded with poliovirus 1 displaced the virus from a carbon bed after a time, and resulted eventually in greater quantities of virus in the effluent than in the influent (84).

In batch tests and in column studies at variable flow rates, activated carbon adsorbed seeded coliphage f2 from trickling filter effluents and from synthetic river water (91).

Disinfection

Since treatment procedures do not remove all viruses from either sewage effluents or water, the safety of such waters is largely dependent on terminal disinfection. The disinfection process is complex, however, and not simple, as many still suppose, and most effluents and many water supplies are therefore inadequately disinfected.

The problem begins with the complexity of the chemistry of chlorine, certainly the most widely used disinfectant for sewage effluents and water. Although it hydrolyses in water to form the strongly virucidal hypochlorous acid (HOCl), chlorine also occurs as hypochlorite ion (OCl^-) at alkaline levels of pH, as ammonia chloramines when ammonia is present, and as organic chloramines when organic nitrogenous compounds are available (35, 67). Since only HOCl is a rapid virucide, the maintenance of chlorine as an effective disinfectant depends on removing ammonia and organic compounds from water and keeping the pH at near-neutral to acid levels. Domestic sewage always contains ammonia; sewage effluents and even finished waters that are free of ammonia and organic compounds are not usual. The pH, usually less of a problem, is often to the alkaline side in natural waters.

Moreover, when chlorine reacts with organic matter, tastes and odours are often produced that are obnoxious to people who have not learned to be tolerant of them. Chlorine is widely accepted as a universal water and effluent disinfectant in some parts of the world, but it is anathema in others.

There would seem to be good reason for selecting disinfectants that are appropriate to each particular job to be done. Despite only limited expressed interest in this procedure (7), a growing interest in disinfectants other than chlorine indicates the direction of things to come.

Chlorine. It has been known for some time that hypochlorous acid is a strong virucide. Although not all of the available data are of good quality, one can glean from many of them at least reasonable approximations of time–concentration–temperature relationships for virus destruction.

Thus, 1 mg of hypochlorous acid per litre destroyed 99.6% of coxsackievirus A2 in about 100 s at 27–29°C, and in about 7 min at 3–6°C. The same concentration of hypochlorite ion destroyed the same amount of the virus in about 3.5 min at 27–29°C, and in about 30 min at 3–6°C (20).

Adenovirus 3, however, appears to be somewhat more sensitive to hypochlorous acid. With this virus, 99.8% were destroyed by 0.1 mg of HOCl per litre in about 20 s at 4°C. The hypochlorite ion was much slower, requiring at this concentration about 150 s at 25°C, and about 200 s at 4°C (22).

Weidenkopf, working with poliovirus 1, found that at 0°C, 99% of the virus was destroyed by 1 mg of hypochlorous acid per litre in about 1 min, and by the same quantity of hypochlorite ion in about 10 min (92).

In a carefully conceived study, Scarpino et al. showed that 1 mg of hypochlorous acid per litre destroyed 99% of poliovirus 1 in about 100 s at 5°C and that an equal amount of hypochlorite ion destroyed the same amount of the virus in about 20 s at the same temperature (78). This apparently anomalous behaviour of the hypochlorite ion is now under careful study. In comparative studies, these workers found that *Escherichia coli* was destroyed much more quickly by the same quantity of HOCl at this temperature, but somewhat more slowly at higher pH levels, presumably by the hypochlorite ion.

Salts also may affect the disinfection process. Sproul et al. reported that increased inactivation

rates occurred with coliphage T2 with increased concentrations of calcium chloride (85).

Combined forms of chlorine were known to be virucidal long before the significance of different chlorine forms was understood. Neefe et al., in a classic paper, showed that chloramines destroyed viral hepatitis A virus, and that a large amount of chlorine was required to destroy this virus in faecal filtrates (68). Others have shown that chlorine may destroy viruses in effluents, but not always (53, 54, 63).

Subsequent studies showed more clearly the need for greater amounts of chlorine when combined forms of chlorine were to be relied upon. Some evidence exists, however, that most viral and bacterial destruction in a chlorinated effluent takes place during the first seconds after the chlorine is added, a period during which HOCl may still briefly exist and thereby be available to disinfect (72, 80). The HOCl, however, had not been measured. Since the amount of chlorine present as HOCl and the period of time during which HOCl persists will vary from effluent to effluent, the large variations reported in the ratio of time and chlorine concentration necessary for a given fraction of virus destruction in effluents may thereby be accounted for. It is possible, however, to account for these variations also by postulating in different effluents the formation of different chloramines (inorganic and organic) or intermediate substances with different virucidal potentials, or by selecting different percentage kill standards that can be misleading with death rate curves that change direction sharply.

In any event, Shuval reported that, in sewage effluent, 99.9% destruction of poliovirus 1 was brought about in 10 min by 40 mg of applied chlorine per litre at 20°C, but that only 9 mg/litre destroyed the same percentage of coliform organisms in similar circumstances (80). An echovirus tested was more sensitive than the poliovirus. Shuval et al. reported earlier that 90% of poliovirus 1 was destroyed at 20°C in 6 h by the application of 11 mg of chlorine per litre (81). Lindeman & Kott recently noted that application of 8 mg of chlorine per litre to Haifa sewage effluents resulted in no decrease of viral numbers after 1 h, although some decrease in numbers occurred after 2 h of contact (58).

Burns & Sproul noted 99% inactivation of coliphage T2 in trickling filter effluents at 20°C when 2.7 mg of residual combined chlorine per litre was detected amperometrically (13). Coliform organisms were destroyed more quickly. Lovcevič & Sergunina reported that *E. coli* was more sensitive than a poliovirus to both free and combined forms of chlorine (60). Subsequently, Lothrop & Sproul reported that residual combined chlorine of 400 mg/litre (measured amperometrically) destroyed 99.99% of poliovirus 1 in 30 min at 20°C in primary effluent (59). Shah & McCamish (79) recently reported that a mixture of ammonia chloramines inactivated poliovirus 1 and coliphage T2 more rapidly than they inactivated coliphage f2.

Chloramines are highly toxic to certain fish and other aquatic species. Chloramine concentrations of 0.06–0.08 mg/litre are lethal to trout. Thiosulfate, however, renders toxic chlorinated compounds nontoxic (95).

Ozone. Although ozone is already used as a water disinfectant in some places, there are few data available on its virucidal efficiency. The limited literature is more qualitative than quantitative but it demonstrates the potential value of ozone as a disinfectant for effluents and water. Ozone is also difficult to measure at the low concentrations required for disinfection.

Seeded coliphage f2 was totally destroyed in 5 min in secondary effluent by 15 mg of applied ozone per litre which left a residual of 0.015 mg/litre (74).

In 10 min, residual ozone of 0.1–0.2 mg/litre inactivated more than 99% of poliovirus 3 and coxsackievirus B3 in water containing organic material (86).

Coin et al. showed that a few tenths of a milligram of ozone per litre destroyed more than 99% of poliovirus 1 in 2–3 min in distilled water (25, 26). In filtered river water, ozone was only slightly less effective.

Jakovleva & Il'nickij reported that adenovirus 7a was more sensitive than *E. coli* to ozone (94). These workers obtained better results at low temperatures than at high temperatures, apparently because they were able to maintain higher ozone concentrations at lower temperatures where its solubility is greater.

Carazzone & Vanini reported that coliphage T1 was destroyed in surface water by 0.5–0.55 mg of ozone per litre in 5 min (14).

Iodine. This has been widely used as a disinfectant for small water supplies, and its bactericidal, cysticidal, and virucidal capabilities have been extensively researched.

In a definitive study on the virucidal capability of iodine in a clean water system, 99% of coxsackie-

virus A9 (the most resistant of the viruses tested) was destroyed by 0.1 milliequivalent of elemental iodine per litre in less than 5 min at 25°C (9). It took four to five times longer to produce the same proportion of viral destruction with the same amount of iodine with each 10°C drop in temperature. *E. coli* and a number of other bacteria were much more sensitive to iodine (Berg et al., unpublished observations, 1963).

Krusé et al. also demonstrated the virucidal capability of iodine (57). They also reported that, unlike hypochlorous acid, elemental iodine did not destroy the nucleic acid of the virus (48).

Several studies have indicated that iodine is safe for human consumption in the concentrations required for disinfection (37, 55, 66).

Bromine. Although used in some places as a swimming pool disinfectant, bromine compounds are not popular as water or effluent disinfectants. Bromine is difficult to handle, but apparently bromamines, as well as hypobromous acid (HOBr), are effective virucides (57). The chemistry of bromine disinfection has been studied intensively by Johnson & Overby (50).

Ultraviolet light. This has long been known to be an effective germicide, but its application to water disinfection has been limited. However, there has been relatively great interest in recent years in applying it to disinfection of depuration waters for shellfish. Ultraviolet light, of course, leaves no residual, is not likely to be highly effective in turbid or coloured waters, and may yet be too expensive for large-scale water operations. Moreover, the build-up of slimes and other opaque materials over the lights may reduce its disinfectant efficiency and bring about high maintenance costs. Nonetheless, there has been sufficient interest in ultraviolet light to stimulate a moderate research effort into its effectiveness as a water virucide.

Hill et al. reported rapid destruction of 7 enteroviruses and 1 reovirus in estuarine water and of poliovirus 1 in seawater by ultraviolet light (45–47). They believe this method to be the best now available for disinfecting depuration waters. 99% of each virus was destroyed in 15–25 s by exposure to 1.16×10^{-5} J of ultraviolet light per mm^2 per second.

Vajdic reported that ultraviolet irradiation of sewage effluent rapidly inactivated a seeded coliphage, but did not destroy all of the virus even after long exposure (90).

Furuse & Watanabe reported that the ultraviolet light sensitivities of phages MS2 and Qβ were different in water, and that there was little difference between the sensitivities of the whole phages and those of their RNAs freed from their coat proteins (38).

Gamma and X-irradiation. Although impracticable for large-scale use at this time, gamma radiation can penetrate particulate matter and may be an excellent water and effluent disinfectant. Rjabčenko & Lovcevič showed that poliovirus 1 and echovirus 7 were more resistant than *E. coli* to gamma radiation in water, requiring 2–3 times the dosage for an equal proportion of destruction (76). Sullivan and his colleagues studied the effect of gamma radiation on 30 viruses and found that 90% destruction could be attained with 0.39–0.53 megarads, the rate of destruction depending on whether the viruses were suspended in distilled water or in an organic medium (87).

Powers & Gampel-Jobbagy noted that ethanol scavenging of OH^- and H^+ in buffered, X-irradiated suspensions of coliphage T7 saturated with N_2, N_2O, or O_2 resulted in partial sparing of the virus, suggesting that in pure suspensions some of the inactivation may be derived from free radical activity (75).

Other disinfectants. Oligodynamic metals may account for a considerable amount of virus inactivation in the water environment, and particularly in certain distribution systems. In laboratory experiments, Jordan & Massar found that infectious bronchitis virus survived for more than 6 h in water that contained less than 0.02 mg of Cu^{2+} per litre, but for only 2 h in similar water that contained 0.2 mg of Cu^{2+} per litre (52). Iron filings or powdered skim milk (to displace the Cu^{2+}) increased virus survival time to at least 6 h. The possible advantage of copper plumbing is evident.

WATER RENOVATION

Water renovation is largely the application of water treatment procedures to wastewaters. Thus, one may expect that much of the laboratory-acquired information on coagulation, rapid sand filtration, carbon adsorption, and disinfection will apply directly to the problem of renovation.

Under the direction of our laboratory there are now under study certain of these processes designated as a renovation train. Few data are at present available, however.

In other efforts, some limited data have become available. In the classic Lake Tahoe renovation plant, viruses were demonstrated in the primary and secondary effluents, and once in the carbon column effluent, but not after chlorination (32).

Nupen could not recover viruses from treated water of the Windhoek reclamation plant, although she had recovered up to 20 000 $TCID_{50}$ of viruses per litre from the sewage influent (70).

In full-scale plant tests with a standard inverted pyramidal upflow system, at a particle settling velocity of 0.5 mm/s, 99–99.9% of the viruses in sewage and 95–99% of the *E. coli* and other coliform organisms present were removed by treatment with 150 mg of aluminium sulfate per litre and 250 mg of powdered carbon per litre (82).

VIRUSES IN SLUDGES

Viruses are readily recovered from sludge, but probably with low efficiency. It is not known at present just how low the efficiency of recovery is, because it is impossible to determine what proportion of viruses adsorbed by sludges is adsorbed irreversibly, what proportion is embedded too deeply to be reached for elution, and what proportion is destroyed by other influences within the sludge environment.

Small numbers of enteroviruses were recovered from sludge by Clarke et al. (23). Mack et al. (63) recovered viruses from sludge samples that they tested, and Lund (61) readily recovered viruses from activated sludge and, in fact, from sludge digesting at 50°C.

Grigor'eva et al. recovered coxsackievirus B5 after 30 days of thermophilic digestion (43, 44). A pathogenic strain of *E. coli* survived for only 10 days under these conditions, and bacterial viruses for an intermediate period.

In studies with viruses and bacteria seeded into fresh and digested sludges, a temperature of 80°C for 10 min brought about reductions of more than 99.99% of poliovirus 1, more than 99% of coxsackievirus B3, and even greater reductions of *Salmonella paratyphi B* (36).

In the activated sludge of a circulating oxidizing channel, seeded coxsackievirus B5 was reduced in concentration by 99% after 3 days, and seeded echovirus 19 was reduced in concentration by more than 99% after 5 days (41).

RÉSUMÉ

ÉLIMINATION DES VIRUS DES EAUX D'ÉGOUT, DES EFFLUENTS ET DES EAUX: 1. REVUE DE LA QUESTION

Tous les procédés de traitement des eaux d'égout et des eaux brutes éliminent ou détruisent des virus. Certaines méthodes sont plus efficaces que d'autres, mais aucune n'est capable de faire disparaître la totalité des virus présents.

Bien que ses effets soient controversés, la sédimentation primaire entraîne probablement la disparition d'un grand nombre des virus présents dans les eaux d'égout, car les virus sont pour une bonne part fixés ou adsorbés sur les matières solides. Leur élimination par sédimentation est plus ou moins proportionnelle à la quantité des matières solides déposées mais il faudrait la mesurer en déterminant le nombre des virus restants dans l'effluent. Le stockage des effluents ou de l'eau pendant de longues périodes a un effet destructeur sur les virus.

L'utilisation des boues activées représente la meilleure méthode biologique d'élimination des virus des eaux d'égout. L'efficacité des filtres et des bassins de stabilisation est irrégulière. Dans le cas des bassins de stabilisation, les échecs sont probablement dus à des phénomènes de court-circuit, car le stockage prolongé, en exposant les virus à diverses substances nocives, au rayonnement ultra-violet et à l'action des matières adsorbantes devrait normalement favoriser leur destruction.

La coagulation utilisant des ions métalliques apparaît, du moins si l'on se réfère aux résultats obtenus en laboratoire, comme la méthode de traitement unique la plus efficace pour éliminer les virus des eaux d'égout et des eaux brutes. La chaux est l'agent coagulant qui convient le mieux à cet effet, à condition d'être ajoutée en quantité suffisante pour obtenir un pH de 11 environ. A ce niveau élevé d'alcalinité, la durée de contact requise pour réaliser la coagulation suffit à inactiver une grande quantité de virus. Les polyélectrolytes entraînent aussi la sédimentation des virus.

La filtration rapide sur sable n'élimine pas les virus, mais la filtration d'effluents coagulés est efficace, probablement parce que le floc en voie de formation adsorbe lui-même les virus. L'argile et le charbon activé ont un certain pouvoir adsorbant, mais leur activité est insuffisante.

En fin de compte, c'est à la désinfection qu'il faut recourir pour obtenir une eau de boisson et des effluents ne contenant pas de virus. Cependant, cette méthode n'est

pas d'application facile et les désinfectants doivent être choisis en fonction des besoins. S'il est relativement aisé de désinfecter une eau parfaitement claire, il n'en va pas de même si l'eau contient des matières organiques ou des substances solides. Il est probable que, dans ce cas, il faudra utiliser la chaleur ou un rayonnement pénétrant. Les eaux destinées à être déversées dans les cours d'eau ne doivent pas être désinfectées à l'aide de produits susceptibles de léser la vie aquatique, à moins que les produits toxiques ne puissent être neutralisés. Quant aux eaux destinées à être consommées comme eaux de boisson, elles doivent contenir un résidu actif.

REFERENCES

1. BAGDASAR'JAN, G. A. *Ž. Mikrobiol. (Mosk.)*, **47** (8): 96 (1970)
2. BAGDASAR'JAN, G. A. & ABIEVA, R. M. *Hyg. Sanit.*, **36** (1-3): 333 (1971)
3. BAGDASAR'JAN, G. A. & KAZANCEVA, V. A. *Hyg. Sanit.*, **30** (7-9): 15 (1965)
4. BENDINELLI, M. ET AL. *Riv. ital. Igiena*, **27**: 198 (1967)
5. BERG, G. *Health Lab. Sci.*, **3**: 90 (1966)
6. Berg, G. *Health Lab. Sci.*, **3**: 170 (1966)
7. BERG, G. *J. san. Eng. Div., ASCE*, **97**: 867 (1971)
8. BERG, G. *In*: Snoeyink, V., ed. Virus and water quality: occurrence and control. Proceedings of the Thirteenth Water Quality Conference, February 1971, *University of Illinois Bulletin* **69**, p. 126 (1971)
9. BERG, G. ET AL. *Virology*, **22**: 469 (1964)
10. BERG, G. ET AL. *J. Amer. Water Works Assoc.*, **60**: 193 (1968)
11. BLOOM, H. H. ET AL. *J. inf. Dis.*, **105**: 61 (1959)
12. BRUNNER, D. R. & SPROUL, O. J. *J. san. Eng. Div., ASCE*, **96**: 365 (1970)
13. BURNS, R. W. & SPROUL, O. J. *J. Water Poll. Cont. Feder.*, **39**: 1834 (1967)
14. CARAZZONE, M. M. & VANINI, G. C. *G. Batt. Virol.*, **62**: 828 (1969)
15. CARLSON, S. *Zbl. Bakt., I. Abt. Orig.*, **212**: 50 (1969)
16. CARLSON, G. F. ET AL. *J. Water Poll. Cont. Feder.*, **40**: R89 (1968)
17. CHANG, S. L. ET AL. *Amer. J. publ. Hlth*, **48**: 159 (1958)
18. CHAUDHURI, M. & ENGELBRECHT, R. S. *J. Amer. Water Works Assoc.*, **62**: 563 (1970)
19. CHAUDHURI, M. & ENGELBRECHT, R. S. *In*: Proceedings of the Fifth International Conference on Water Pollution Research 1970. New York, Pergamon, p. II-20 (1971)
20. CLARKE, N. A. & KABLER, P. W. *Amer. J. Hyg.*, **59**: 119 (1954)
21. CLARKE, N. A. ET AL. *J. Amer. Water Works Assoc.*, **48**: 677 (1956)
22. CLARKE, N. A. ET AL. *Amer. J. Hyg.*, **64**: 314 (1956)
23. CLARKE, N. A. ET AL. *Amer. J. publ. Hlth*, **51**: 1118 (1961)
24. CLARKE, N. A. ET AL. *In*: Proceedings of the First International Conference on Water Pollution Research 1962. New York, Pergamon, p. 523 (1964)
25. COIN, L. ET AL. *Presse méd.*, **72**: 2153 (1964)
26. COIN, L. ET AL. *Presse med.*, **75**: 1883 (1967)
27. COOKSON, J. T., Jr. *Environ. Sci. Technol.*, **1**: 157 (1967)
28. COOKSON, J. T., Jr. *J. Amer. Water Works Assoc.*, **61**: 52 (1969)
29. COOKSON, J. T., Jr. *Environ. Sci. Technol.*, **4**: 128 (1970)
30. COOKSON, J. T., Jr. *J. Water Poll. Cont. Feder.*, **42**: 2124 (1970)
31. COOKSON, J. T., Jr. & NORTH, W. J. *Environ. Sci. Technol.*, **1**: 46 (1967)
32. CULP, R. L. *Pub. Works*, **102**: 84 (1971)
33. DREWRY, W. A. & ELIASSEN, R. *J. Water Poll. Cont. Feder.*, **40**: R257 (1968)
34. ENGLAND, B. ET AL. *In*: Berg, G., ed. Transmission of viruses by the water route, New York, John Wiley, p. 401 (1967)
35. FAIR, G. M. ET AL. *New Engl. Water Works Assoc.*, **61**: 285 (1947)
36. FOLIGUET, J.-M. & DONCOEUR, F. *Water Res.*, **6**: 1399 (1972)
37. FREUND, G. ET AL. *J. clin. Endocr.*, **26**: 619 (1966)
38. FURUSE, K. & WATANABE, I. *Virology*, **46**: 171 (1971)
39. GILCREAS, F. W. & KELLY, S. M. *J. Amer. Water Works Assoc.*, **47**: 683 (1955)
40. GLOBA, L. I. ET AL. *Dopov. Akad. Nauk Ukr. SSR, Ser. B.*, **33**: 1036 (1971)
41. GONČARUK, E. I. ET AL. *Hyg. Sanit.*, **35**: (1-3): 36 (1970)
42. GRIGOR'EVA, L. V. & GONČARUK, E. I. *Hyg. Sanit.*, **31** (10-12): 158 (1966)
43. GRIGOR'EVA, L. V. ET AL. *Hyg. Sanit.*, **33** (7-9): 360 (1968)
44. GRIGOR'EVA, L. V. ET AL. *Mikrobiol. Ž.*, **31**: 659 (1969)
45. HILL, W. F. ET AL. *Appl. Microbiol*, **17**: 1 (1969)
46. HILL, W. F. ET AL. *Appl. Microbiol.*, **19**: 805 (1970)
47. HILL, W. F. ET AL. *J. san. Eng. Div., ASCE*, **97**: 601 (1971)
48. HSU, Y. *Nature*, **203**: 152 (1964)
49. ISHERWOOD, J. D. *Amer. J. publ. Hlth*, **55**: 1945 (1965)
50. JOHNSON, J. D. & OVERBY, R. *In*. Proceedings of the National Specialty Conference on Disinfection, July 1970, ASCE, p. 37 (1971)
51. JOHNSON, J. H. ET AL. *Nature*, **213**: 665 (1967)

52. JORDAN, F. T. W. & MASSAR, T. J. *Vet. Rec.*, **89**: 609 (1971)
53. KELLY, S. & SANDERSON, W. W. *Sewage & indus. Wastes*, **31**: 683 (1959)
54. KELLY, S. ET AL. *Water Poll. Cont. Feder.*, **33**: 1056 (1961)
55. KINMAN, R. N. ET AL. *In*: Proceedings of the National Specialty Conference on Disinfection, July 1970, ASCE, p. 11 (1971)
56. KISELEVA, L. F. *Hyg. Sanit.*, **33** (7–9): 439 (1968)
57. KRUSÉ, C. W. ET AL. *In*: Proceedings of the National Specialty Conference on Disinfection, July 1970, ASCE, p. 113 (1971)
58. LINDEMAN, S. & KOTT, Y. *Israel J. med. Sci.*, **7**: 1111 (1971)
59. LOTHROP, T. L. & SPROUL, O. J. *J. Water Poll. Cont. Feder.*, **41**: 567 (1969)
60. LOVCEVIČ, E. L. & SERGUNINA, L. A. *Hyg. Sanit.*, **33** (7-9): 334 (1968)
61. LUND, E. *In*: Proceedings of the Fifth International Conference on Water Pollution Research 1970, New York, Pergamon, p. I-24 (1971)
62. LUND, E. *In:* Proceedings of the Sixth International Conference on Water Pollution Research 1972, New York, Pergamon (1973)
63. MACK, W. N. ET AL. *J. Water Poll. Cont. Feder.*, **34**: 1133 (1962)
64. MALHERBE, H. H. & STRICKLAND-CHOLMLEY, M. *In*: Berg, G., ed. Transmission of viruses by the water route. New York, John Wiley, p. 379 (1967)
65. MANWARING, J. F. ET AL. *J. Amer. Water Works Assoc.*, **63**: 298 (1971)
66. MORGAN, D. P. & KARPEN, R. J. *U.S. armed Forces med. J.*, **4**: 725 (1953)
67. MORRIS, J. C. *In*: Proceedings of the National Specialty Conference on Disinfection, July 1970, p. 609 (1971)
68. NEEFE, J. R. ET AL. *J. Amer. med. Assoc.*, **128**: 1076 (1945)
69. NESTOR, I. & COSTIN, L. *J. Hyg. Epidem. (Praha)*, **15**: 129 (1971)
70. NUPEN, E. M. *Water Res.*, **4**: 661 (1970)
71. OLIFSON, L. E. ET AL. *Hyg. Sanit.*, **35** (9–12): 412 (1970)
72. OLIVIERI, V. P. ET AL. *J. san. Eng. Div., ASCE*, **97**: 661 (1971)
73. PÁLFI, Á. ET AL. *Egészégtudomány*, **14**: 127 (1970)
74. PAVONI, J. L. ET AL. *Water & sewage Works*, **119**: 59 (1972)
75 POWERS, E. L. & GAMPEL-JOBBAGY, Z. *Int. J. radiat. Biol.*, **21**: 353 (1972)
76. RJABČENKO, V. A. & LOVCEVIČ, E. L. *Hyg. Sanit.*, 30 (7–9): 198 (1965)
77. ROBECK, G. G. ET AL. *J. Amer. Water Works Assoc.*, **54**: 1275 (1962)
78. SCARPINO, P. V. ET AL. *Water Res.*, **6**: 959 (1972)
79. SHAH, P. C. & MCCAMISH, J. *Appl. Microbiol.*, **24**: 658 (1972)
80. SHUVAL, H. I. Developments in water quality research. Ann Arbor, Ann Arbor-Humphrey Science Publishers, p. 47 (1970)
81. SHUVAL, H. I. ET AL. *In*: Proceedings of the Third International Conference on Water Pollution Research 1965. New York, Pergamon, p. 37 (1966)
82. SLACK, J. G. *Water Treat. & Exam.*, **21**: 239 (1972)
83. SPROUL, O. *In :* Virus and water quality: occurrence and control, Proceedings of the Thirteenth Water Quality Conference, *University of Illinois Bulletin*, **69**: 159 (1971)
84. SPROUL, O. J. ET AL. *In*: Proceedings of the Fourth International Conference on Water Pollution Research 1968. New York, Pergamon, p. 541 (1969)
85. SPROUL, O. J. ET AL. *In*: Proceedings of the National Specialty Conference on Disinfection, July 1970, p. 385 (1971)
86. SUČKOV, B. P. *Hyg. Sanit.*, **29** (6): 24 (1964)
87. SULLIVAN, R. ET AL. *Appl. Microbiol.*, **22**: 61 (1971)
88. THAYER, S. E. & SPROUL, O. J. *J. Amer. Water Works Assoc.*, **58**: 1063 (1966)
89. THORUP, R. T. ET AL. *J. Amer. Water Works Assoc.*, **62**: 97 (1970)
90. VAJDIC, A. H. *Water Poll. Cont.* (Ontario Water Resources Comm.), **108**: 24 (1970)
91. WATSON, J. T. & DREWRY, W. A. *Water Resources Research Center Report No. 14*, Department of Civil Engineering Research Series No. 11, University of Tennessee (1971)
92. WEIDENKOPF, S. J. *Virology*, **5**: 56 (1958)
93. Wentworth, D. F. ET AL. *J. Amer. Water Works Assoc.*, **60**: 939 (1968)
94. JAKOVLEVA, G. P. & IL'NICKIJ, A. P. *Hyg. Sanit.*, **32** (10–12): 330 (1967)
95. ZILLICH, J. A. *J. Water Poll. Cont. Feder.*, **44**: 212 (1972)