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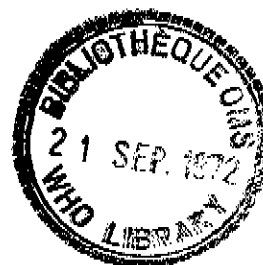
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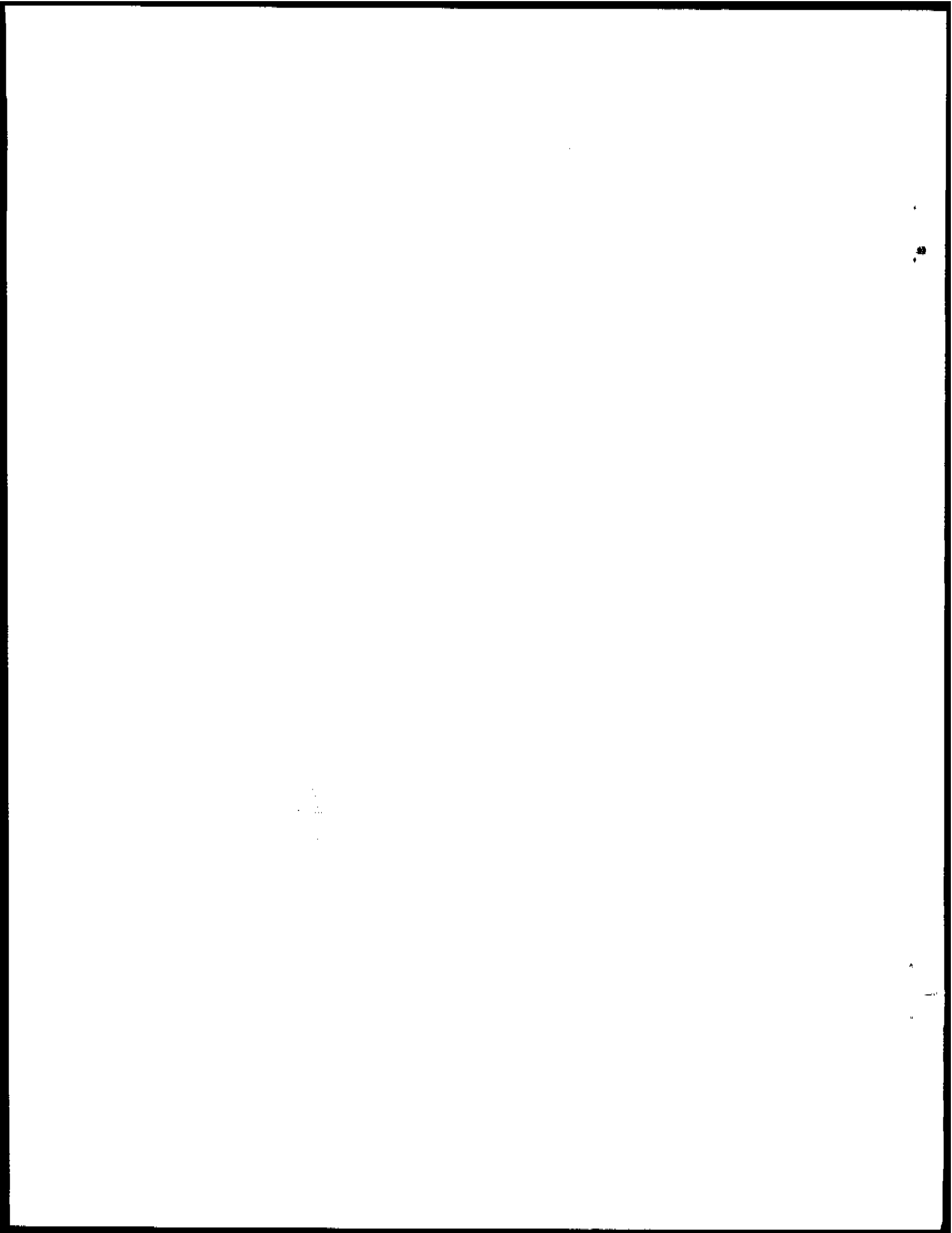
COLLATION OF INFORMATION ON METHODS OF PREVENTING THE
RELEASE TO THE MARINE ENVIRONMENT OF CERTAIN
POTENTIALLY HARMFUL CHEMICALS

Prepared for World Health Organization

by

the Water Pollution Research Laboratory
Stevenage, Herts, United Kingdom





DEPARTMENT OF THE ENVIRONMENT
WATER POLLUTION RESEARCH LABORATORY

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1. INTRODUCTION

The following review summarizes information available on the removal of chemical substances from wastes during treatment of sewage by conventional combinations of physical and biological processes, and on the amounts which can be tolerated without harm to the processes. Possible means of restricting the release of some of the potentially more harmful substances which can penetrate conventional processes are also suggested. It should be appreciated that in practice removal may be better or worse, or the toxic concentration lower or higher, than that implied by the information, because local circumstances such as the efficiency of the particular sewage works and the degree of acclimatization that can be achieved, will vary. When it is necessary to reduce the concentration of some constituent of a sewage effluent this is often most economically achieved by removal of this constituent from trade effluent by pre-treatment at source.

The substances listed have been chosen as being the ones on which information has been most frequently requested in the United Kingdom from the Information Service on Toxicity and Biodegradability (INSTAB) of the Water Pollution Research Laboratory, Stevenage, England. This is probably a reasonable local basis for the establishment of such a list of substances important in waste treatment; there are currently no data available for the construction of a list based more directly on world usage.

The substances have been broadly classified in four groups: inorganic chemicals (listed under the important element or ion - e.g. arsenic, sulphide), organic chemicals, pesticides, and surfactants. In the case of the last two the time available has allowed only a very brief survey and a broad classification of the types available to be made, together with an indication (sometimes only a tentative one because of the absence of adequate data) of their biodegradability and toxicity in treatment processes. An attempt has been made where possible to assess acceptable levels in sewage but, quite apart from the lack of suitable information, conditions vary so much that this can be regarded only as a rough guide; these levels do not allow for protection of receiving waters.

A selection of references is given; this does not cover the literature comprehensively but gives a reasonable coverage of the information surveyed. The review is of necessity an incomplete one, but it should give an overall view of some of the more important aspects of the problem of the discharge of chemical substances either directly through pipelines or via rivers and estuaries to the sea.

Note. In the following pages the dagger mark after a substance heading denotes that an annotated bibliography on the behaviour of the substance in aerobic and anaerobic sewage-treatment processes is available.

2. INORGANIC CHEMICALS

Ammonium†

Ammonium salts present in sewage and trade wastes of neutral pH values are generally dealt with at sewage works without much difficulty, and processes have been known to acclimatize to at least 6000 mg/l of ammoniacal nitrogen. Ammonia also results from breakdown of nitrogenous organic compounds. In fully-nitrifying plants, ammonia is oxidized by bacteria to nitrate, but many compounds inhibit this oxidation and, where it is necessary to restrict the ammonia content of an effluent, the conditions of treatment at the sewage works need careful control; these are now well understood.

Where it is necessary to remove inorganic nitrogen in any form, concentration of ammonia can be reduced by counter-current stripping with air after addition of alkali to raise the pH value to a favourable range, or by ion-exchange; but such processes are expensive, especially if a high degree of removal is required.

References

Ashmore, Catchpole, and Cooper, 1967; Downing, Jones, and Hopwood, 1965; Downing, Painter, and Knowles, 1964; Tomlinson, Boon, and Trotman, 1966.

Antimony

Quite low concentrations of antimony salts would inhibit oxidation of carbonaceous matter: although the levels affecting aerobic sewage-treatment processes have not been determined, a concentration of 0.5 mg/l has been found in USSR to inhibit the BOD determination. Antimony forms insoluble compounds in natural waters and therefore does not persist in solution except in the very low concentrations satisfying solubility product relationships. Its fate is otherwise unknown. If it were necessary to reduce the concentration of antimony in a sewage effluent this would be best achieved by pre-treatment of the trade waste water before discharge to the sewer, for example by co-precipitation with a hydrous metal oxide. Hydrous manganese dioxide would probably be most effective.

Reference

Arzamastsev, 1964.

Arsenic†

Neither arsenates (e.g. Na_3AsO_4) nor arsenites (e.g. NaAsO_2) are particularly toxic to aerobic treatment processes, but at least the former (there is no information about the latter) have to be restricted to low levels in sewage at works where anaerobic digestion is employed; the exact threshold toxic level is uncertain but is probably below 2 mg/l in sewage. The amount of removal by sewage sludges is also uncertain, but may be appreciable. - 3 -

In order to reduce the concentration of arsenic in a sewage effluent the arsenic-bearing waste waters should preferably be treated at source before discharge to the sewer. Laboratory tests have indicated that a high proportion (70-85 per cent) of arsenic in a raw water supply could be removed by cold-time softening of the water and filtration through activated carbon. Passage through ferrous sulphide followed by addition of bone carbon, settlement and filtration through sand and coke is reported to reduce the concentration of arsenic in waste waters from 0.8 mg/l to only 'a trace'.

References

Hermann, 1959; Heukelekian, 1947; Rudolf's, 1937; Tomlinson, Boon, and Trotman, 1966.

Beryllium

The fate and toxicity to treatment processes of this extremely toxic metal are unknown; in USSR, 0.01 mg/l has been reported as the threshold concentration inhibiting BOD. As beryllium is chemically very similar to aluminium it is possible that it could be removed from waste waters by precipitation with aluminium as the hydroxide in the presence of ammonium salts. Although very toxic to mammals, its toxicity to bacteria may be greatly reduced in the presence of organic matter.

Reference

Lebedeva, 1960.

Boron

Very nearly all the boron in borates and similar inorganic compounds entering a sewage works reaches the stream to which the effluent is discharged virtually unchanged. Evidence so far suggests that the fairly low concentrations to be expected do no harm to the treatment processes;

harmful effects would probably not occur at least until levels above 100 mg/l as boron were present. However, concentrations of boron in soil water exceeding 0.5 mg/l are harmful to certain crops, particularly soft fruits. Thus only a relatively low concentration can be tolerated in river water used for irrigation purposes, and for similar reasons the concentration of boron in liquid digested sewage sludge and other sludges applied to land must be limited. It is recommended that the maximum rate of application of boron to land should not exceed 4.5 kg/ha year. Boron may be removed from waste waters by absorption in strongly basic anion-exchange materials at pH values between 7.5 and 9.0. More specifically, ion-exchange resins which are highly selective for the removal of borate and boric acid can be used.

Reference

Waggott, 1969.

Cadmium†

Cadmium is one of the most toxic metals for sewage-treatment processes, but has not been studied as extensively as others such as copper and zinc. The extent of its removal by sludges has not yet been definitely determined, but it is reported to be considerable at low concentrations (e.g. 97 per cent at 0.09 mg/l at one works, and 85 per cent at 2.1 mg/l by treatment in percolating filters). The tentative acceptable level purely from the standpoint of toxicity to treatment processes, ignoring subsequent effects on the stream and taking no account of the presence of other toxic metals, would be of the order of 2 or 3 mg/l when continuously present. However there is no reason why more than a few parts per million of the more costly heavy metals present in waste waters should be discharged to sewers: water and metals can be reclaimed by processes such as electrolysis and ion exchange, and the relatively small amounts which cannot be recovered

in these ways can be precipitated as hydroxides or basic carbonates by controlled addition of alkalis such as sodium hydroxide, lime, or sodium carbonate. The addition of coagulants (e.g. aluminium sulphate, ferric chloride, or polyelectrolytes) can improve the efficiency of separation of the hydroxides by settlement, and residual suspended matter can be removed by filtration through beds of sand. The concentration of cadmium may be reduced to 2 mg/l by precipitation at pH 9-10 and settlement, and to less than 1 mg/l if sand filtration is also provided.

References

Burrows, 1968, Heukelekian and Gellman, 1955; Mosey, Swanwick, and Hughes, 1971; Pettet, 1956; Tenny and Stanley, 1967.

Chromium†

Chromium may be discharged in wastes in two different forms, hexavalent (e.g. chromates, dichromates) or trivalent (chromic salts, such as the sulphate). The latter form is precipitated at the works and only reaches a river in association with solids which escape removal; the former, however, is not removed to such an extent, and amounts reported to be removed at sewage works vary between about 35 to about 80 per cent. Studies on chromium have been very extensive and it is now agreed that 10 mg/l of hexavalent chromium alone in a sewage influent would not greatly affect a normal works; this value, however, is generally reduced to 1 mg/l in order to maintain an acceptable level in the works effluent.

Chromium is a relatively expensive metal and economical reclamation may be possible from waste waters at source. Hexavalent chromium may be reduced to the trivalent state by treatment with sulphur dioxide at a pH value below 3.0. Adjustment of the pH value to 7.5 will then precipitate

chromic hydroxide which can be removed by settlement to leave less than 1 mg/l in solution.

References

Bailey, Dorrell, and Robinson, 1970; Barth et al., 1963; Barth et al., 1965a, 1965b; English et al., 1964; Ingols, 1954; Jenkins and Hewitt, 1940, 1942; Lawson and Fearn, 1970; Masselli, Masselli, and Burford, 1967; Mosey, Swanwick, and Hughes, 1971; Pettet, 1956; Stones, 1955; Tomlinson, Boon, and Trotman, 1966.

Copper†

Removal of copper during sewage treatment is only moderate, as in the case with hexavalent chromium; the amounts of removal reported vary from about 40 to about 80 per cent. The acceptable level in sewage at a treatment works would be not more than 0.3 or 0.4 mg/l. The presence of copper in sludge digestion and disposal is a matter of concern, being considerably more toxic than chromium both to treatment processes and crops.

Many methods are available for the reclamation of copper from waste waters at source: these include electrolysis, ion exchange, and cementation with iron. Residual copper in solution can be precipitated at pH 8 by alkalis.

References

Anon, 1956; Barth et al., 1963; Barth et al., 1965a, 1965b; Burrows, 1968; Department of Scientific and Industrial Research, 1963; Lawrence and McCarty, 1965; Lawson and Fearn, 1970; Masselli, Masselli, and Burford, 1961; Mosey, Swanwick, and Hughes, 1971; Pettet, 1956; Salotto et al., 1964; Stones, 1958; Tomlinson, Boon, and Trotman, 1966.

Cyanide†

Although cyanides are potentially more toxic to sewage-treatment processes than most heavy metals, the processes can be acclimatized to treat relatively large amounts with complete destruction of the cyanide

present. Under suitable conditions as much as 350 mg/l or even more of cyanide can be destroyed effectively. In surface waters cyanide is removed both chemically and biologically, the rate depending on pH value, light intensities, and temperature.

Complex cyanides have not been studied so thoroughly, but cupro- and nickelo-cyanides are only partially destroyed in filters (about 75 per cent destruction of the cyanide) and ferrocyanides are, apart from being oxidized to ferricyanides, not attacked. These, together with the zinc complexes, all release cyanide in surface waters; ferrous cyanide is first converted to ferric ferrocyanide in sunlight, and at pH values below 8 hydrogen cyanide is lost from solution by volatilization. Cyanides and many of its complexes are often most suitably destroyed by alkaline chlorination; however, ferricyanide cannot be removed in this way and is normally precipitated by 'copperas' (ferrous sulphate) in the presence of lime. Biological treatment of cyanides is less effective at extremes of temperatures (above 35°C and below 10°C) and unexpected 'slug' doses will inhibit nitrification.

References

Ashmore, Catchpole, and Cooper, 1967; Barnes and Braidech, 1942; Lautenbach, 1966; Lockett and Griffiths, 1947; Ludzack and Schaffer, 1962; Lure and Panova, 1964; Murphy and Nesbitt, 1964; Pettet and Mills, 1954; Pettet and Thomas, 1948; Ware, 1958.

Fluorides

The solubility of calcium fluoride in distilled water at normal temperatures is about 9 mg/l as fluoride; in hard water its solubility would be about 2 mg/l. Solubility increases with salinity. It is not possible, therefore, to predict the chemical removal of fluorides during sewage treatment. Removal by biological treatment from sewage containing up to 3.6 mg/l of fluoride has been reported in one case to be about 57 per cent. Amounts of fluoride up to at least 30 mg/l have been

found not to inhibit treatment by biological filtration (WPRL, unpublished data), but the possibilities that they may have an adverse effect on scouring organisms (metazoa) present in a filter cannot be ruled out. It would seem that although a considerable proportion of the fluoride present in a waste would reach the stream to which the effluent is discharged, much would be subsequently removed from solution in river water and hard water, and rather less in soft water. However, fluoride might remain in solution in saline conditions, in estuaries and the sea.

High concentrations of fluoride (more than 20 mg/l) in water can be reduced by precipitation by lime followed by sedimentation. Residual traces of fluoride can be removed if necessary by absorption on activated alumina which can be subsequently regenerated.

References

Department of Scientific and Industrial Research, 1954, 1955; Masuda, 1963; Terhoeven and Kuchhoft, 1949; Zabban and Jewett, 1967.

Lead †

Lead is usually precipitated in natural surface waters. Removal during sewage treatment would probably be considerable, but there is only one published report about this: sedimentation removed 30 per cent of lead from concentrations of 0.3-0.9 mg/l; biological filtration and the activated-sludge process removed 30 and 90 per cent respectively from settled sewage. It is likely that the concentration of lead and other heavy metals in a biologically treated sewage effluent could be significantly reduced by addition of lime to pH 8.5 or higher, followed by settlement. Lead is not particularly troublesome to sludge digestion.

Complexed lead in solution in waste waters can be released by chlorination or ozonization and the lead then precipitated from alkaline solution before the waste waters are discharged to sewers. Small amounts remaining in suspension after gravity settlement can be removed by sand filtration.

References

Mosey, Swanwick, and Hughes, 1971; Stones, 1960.

Mercury†

Mercury occurs in wastes as the metal, and as inorganic and organic compounds. The metal is appreciably soluble in water containing dissolved oxygen. Inorganic mercury is known to be strongly adsorbed by organic matter and therefore removal during sewage treatment is likely to be considerable. The fate of organic mercury is uncertain, but appreciable adsorption is likely to occur. Although inorganic mercury is one of the most toxic metals to BOD, in treatment practice adsorption causes a considerable reduction in toxicity and as much as 100 mg/l has been tolerated by an activated-sludge process without inhibition of nitrification taking place.

There are no data available about organic mercury compounds. If they are biodegradable they would release inorganic mercury which would be subsequently bound on organic matter if this were present. However, it is known that such mercury remains biologically available, so the question whether or not organic mercury compounds are biodegradable is mainly of academic interest and not practically important. It would seem therefore that effective control of mercury pollution would not be achieved solely by biological sewage treatment and the aim must be to control the discharge of all forms of mercury into liquid wastes.

Reference

Department of the Environment, 1971.

Nickel†

Removal of nickel during sewage treatment is usually poor. Published reports show that removal varies from about 30 to about 80 per cent, most reports giving values in the lower part of this range. The acceptable concentration for sewage treatment for nickel alone would be about 2 mg/l,

when continuously present. Nickel is not so toxic to sludge digestion as copper and zinc, but as it is much more harmful to plants than either, its presence is of considerable importance in sludge disposal.

Nickel, like other toxic heavy metals, is best removed at source. Precipitation at pH 10.5 has been recommended. It should be possible to reduce the concentration of dissolved nickel to about 0.05 mg/l by precipitation at this pH value followed by settlement. It is advantageous to add a ferric salt in order to improve filtration properties.

References

Barth et al., 1963; Barth et al., 1965a, 1965b; Burrows, 1968; Lawrence and McCarty, 1965; Lawson and Fearn, 1970; Mosey, Swanwick and Hughes, 1971; Pettet 1956; Stones, 1959; Tomlinson, Boon and Trotman, 1966.

Sulphide

Sulphide is oxidized to sulphate during aerobic treatment, but can be toxic at fairly low concentrations. Values reported for toxic levels vary from 25 mg/l upwards and at least 200 mg/l can sometimes be treated; the acceptable level depends on the degree of acclimatization that can be achieved. The combination of sulphide and cyanide is particularly inhibitory. The presence of sulphide in sewage sludges helps to reduce heavy metal toxicity in anaerobic digestion.

Other possible methods of treatment are the chemical oxidation by chlorine to sulphates, or more cheaply by air in the presence of manganous ions as catalyst to form thiosulphate.

References

Ashmore, Catchpole, and Cooper, 1967; Bell and Jones, 1965; Lawrence, McCarty, and Guerin, 1964; Masselli, Masselli, and Burford, 1967.

Sulphite

Sulphite is oxidized to sulphate; its main importance in sewage treatment and in surface waters is its rapidly exerted oxygen demand. Chemical oxidation of sulphite by dissolved oxygen is effectively catalysed by small concentrations of cobalt salts.

Thiocyanate†

Thiocyanate is relatively stable in natural waters, but is fairly easily destroyed during sewage treatment. The toxic levels depend very much on conditions and amounts as low as 5 mg/l of thiocyanate have been reported as toxic. On the other hand, 300 mg/l has been reported as not affecting nitrification and 500 mg/l as being completely destroyed during treatment. In addition to oxidation in biological treatment plants, thiocyanate can be destroyed by treatment with ozone or by alkaline chlorination.

References

Ashmore, Catchpole, and Cooper, 1967, 1968; Gwilliam, Crudge, and Jenkins, 1954; Ludzack and Schaffer, 1962; Schönborn and Lautenbach, 1966; Tomlinson, Boon, and Trotman, 1966.

Tin†

Inorganic tin is of lower toxicity to aerobic process than most other toxic metals, being of a similar order of toxicity to lead; at least 20 mg/l may be tolerated by the activated-sludge process. Tin is similar to lead in forming insoluble compounds in natural waters and would not normally therefore pose a hazard to streams. Organic compounds of tin can be very toxic to micro-organisms; information about them is sparse, however, but it is suspected that they would be difficult to degrade biologically.

Tin can be recovered as metastannic acid from waste waters containing sodium stannate using hydrogen cation-exchange materials. Residual tin can be precipitated at pH 9.

reference

Titanium

There is no information available on titanium, but it may be said that soluble titanium compounds would no doubt prove to be toxic to aerobic processes in the same ways as the 'heavy metals' are. Insoluble compounds, e.g. titanium dioxide, would not, of course, be a hazard in sewage treatment.

Soluble titanium salts in acid solution can be removed by techniques similar to those for other heavy metals, namely neutralization and settlement.

Vanadium

The pentavalent vanadium ion (that is, in basic solution, VO_4^{3-}) is no doubt toxic to micro-organisms, but there is no information available about its behaviour during sewage treatment. pH values of 6.8 or less, vanadium pentoxide is precipitated. The reduced form of vanadium, vanadyl (VO^{2+}), is probably also toxic, but might in any case be oxidized to pentavalent vanadium under aerobic conditions. A concentration of 5.6 mg/l of pentavalent vanadium (as vanadium) has been reported to inhibit the BOD of a surface water.

Vanadyl ions may be removed from waste waters by co-precipitation with ferric hydroxide. The method is most efficient when the metal ions are in the ratio 3:5.

Reference

Selyankina, 1961.

Zinc†

It appears that about 60 to 90 per cent of the zinc present in sewage would normally be removed during treatment. Although relatively high concentrations (25 mg/l or even more) can be tolerated by the activated-sludge process, removal is poor at such levels, and the usual acceptable level would be 1 or 2 mg/l, zinc being very toxic to anaerobic digestion and of major importance in the disposal of sludges.

Zinc can be precipitated from waste waters at pH 9 and the hydroxide separated by settlement; a residual concentration of about 3 mg/l can usually be achieved.

References

Barth et al., 1963; Barth et al., 1965a, 1965b; Burrows, 1968; Department of Scientific and Industrial Research, 1963; Lawrence and McCarty, 1965; Lawson and Fearn, 1970; Mather, 1964; Mosey, Swanwick, and Hughes, 1971; Pettet, 1956; Stones, 1959; Swanwick and Bruce, 1965.

3. PESTICIDES

If the experience of the WPRL Information Service on Toxicity and Biodegradability (INSTAB) is a reliable guide, only a very small number of pesticides (about 20) have been regarded as a problem at sewage-treatment works or in rivers in the United Kingdom, and some of these problems (e.g. accumulation in sewage sludges disposed to land) are outside the scope of this survey.

Highly persistent or fairly persistent pesticides (organochlorine insecticides, triazine herbicides, polychlorinated biphenyls, some organophosphorus compounds, nitrophenols and other nitro-compounds, etc, can be regarded as also resistant to breakdown at sewage works (or subsequently in rivers) although appreciable removal in some cases by sorption on sludges or on bottom deposits in streams may occur; this, however, does not always imply that they are no longer available in the biosphere. Other pesticides that are regarded as rapidly biodegradable ('non-persistent') in field use would probably be fairly readily destroyed during sewage treatment. These include carbamate insecticides, some (but not all) chlorinated phenoxyalkanoic acid and urea-derived herbicides, many organophosphorus compounds, 'natural' insecticides, such as allethrin, pyrethrum and rotenone (derris); bipyridylium herbicides are probably entirely adsorbed by sludges without breakdown. Metallo-organic compounds, e.g. mercury, tin, should be regarded as being in the first

category; discharges of these, particularly of the former, if known about, would probably be refused by the appropriate authorities in the United Kingdom, but manganese and iron compounds, for example, would not be so severely regarded.

Unfortunately little work has been published on the fate of pesticides in sewage treatment and what there is hardly permits of more definite statements to be made than those above. As far as toxicity to treatment processes are concerned, discharges of insecticides, fungicides and bactericides would need strict control, while herbicides would normally be more readily acceptable. Until more specific information is available, each material has to be treated on its merits from a knowledge of the amount used, its behaviour in soil and its known toxicological properties: at the moment, however, such knowledge at best only allows an intelligent guess to be made.

A few pesticides which have received a fair amount of attention under INSTAB enquiries are dealt with separately in the General Organic Chemicals section of this report following.

A wide variety of pesticides can be removed from waste waters by adsorption on activated carbon and destroyed during the subsequent thermal regeneration of the carbon at 750°C. Where possible this treatment should be provided ahead of biological treatment. A plant treating effluent from a factory manufacturing pesticides has been described in which over 90 per cent of the aromatic constituents were removed from the waste water treated at a rate of 220 m³/tonne activated carbon.

Reference

Sharp and Lamden, 1955.

4. GENERAL ORGANIC CHEMICALS

Many organic chemicals are easily degraded by bacteria and the most economic method of destruction is usually by biological oxidation in conventional and modified plants similar to those used for the treatment of sewage. A period of acclimatization is often necessary for the development of suitable numbers and strains of micro-organisms before many of these chemicals can be oxidized efficiently. The presence of other organic compounds which are toxic to bacteria or protozoa or both, or which can only be degraded very slowly, necessitates the use of more costly methods of treatment such as adsorption on activated charcoal (e.g. pesticides), pre-treatment by chemical oxidation using chlorine or ozone or, in some cases, reduction. It may be convenient to remove small concentrations of volatile organic compounds by steam- or air-stripping and burning.

Acetic acid†

Acetic acid is readily destroyed during sewage treatment, the acceptable level being mainly determined by the BOD load that can be tolerated by the plant. Under normal conditions, it is of course of low toxicity to the anaerobic digestion of sewage sludges. However, slug doses of acetic acid to sewage works increasing the concentration of volatile organic acids in the sludge to over 1000 mg/l may inhibit the second stage of anaerobic digestion unless the condition is corrected by addition of lime.

References (selected)

Gerhold and Kalaney 1966; Kocfer and Urtes, 1962; Kumke, Hall, and Oeben, 1968; McCarty and McKinney, 1961, Wilson, 1954.

Acetone†

Acetone is biodegradable; a period of acclimatization is sometimes necessary before efficient removal can be achieved, particularly at higher loadings. Nitrification may be affected by high concentrations

of the solvent, the precise threshold level of inhibition being uncertain, though 2000 mg/l has been reported to produce 75 per cent inhibition in activated sludge. Generally speaking, however, acetone can be regarded as of low toxicity.

References

Gerhold and Malaney, 1966; Kumke, Hall, and Oeben, 1968; Ministry of Technology, 1965a; Tomlinson, Boon, and Trotman, 1966; Young, Ryckman, and Buzzell, 1968.

Acetonitrile†

Acetonitrile is apparently rather difficult to destroy during sewage treatment, but after acclimatization and under suitable conditions it may be removed to at least some extent. (A relatively low sludge loading achieved by provision of a relatively long period of retention and a high concentration of activated sludge and the use of the complete-mixing type of plant provide the most favourable conditions for successful destruction of this class of substance.) There is evidence that at low concentrations breakdown is slow. The nitrile may also be toxic to both aerobic and anaerobic processes, being stable in the latter, but the acceptable level is uncertain. It is suggested that concentrations be kept as low as possible and, as is always desirable with compounds that are potentially toxic and difficult to degrade, that the concentration in the sewage reaching the treatment works should be built up gradually and then be kept as constant as practicable.

References

Chekhovskaya et al., 1966; Ludzack, Schaffer, and Bloomhuff, 1961; Ludzack et al., 1959; Lutin, 1970; Placak and Ruchhoft, 1947.

Acrylamide†

This compound may be discharged separately or occur as an impurity in polyacrylamides; for some purposes (e.g. water treatment) the monomer content of the polymer is strictly controlled. It can be treated

biologically at very low concentrations (0.1 or 0.2 mg/l) but may be toxic at higher levels (WPRL, unpublished data). There is some evidence, however, that higher amounts (50 mg/l) can be oxidized in river water after acclimatization. Information, however, is sparse and its general fate during sewage treatment remains uncertain.

Reference

Cherry, Gabaccia, and Senn, 1956.

Acrylic acid†

Acrylic acid, one of the raw materials used in plastics manufacture, is readily destroyed during aerobic sewage treatment, though a period of acclimatization may sometimes be necessary. Toxicity is not very great and a concentration of 100 mg/l may be acceptable. It is not known whether or not toxic levels can accumulate on sludges to affect digestion, but this compound would not be regarded as a particularly hazardous compound in this respect.

References

Kunke, Hall, and Oeben, 1968; Pahren and Bloodgood, 1961; Stack, 1957.

Acrylonitrile†

After suitable acclimatization of the microflora, acrylonitrile can be destroyed by biological treatment, for example in polymerization waste waters. Evidence suggests that levels above about 40 or 50 mg/l will normally be toxic and that removal is retarded at low temperatures. It might be necessary to restrict concentrations at sewage works where anaerobic digestion is employed, as direct-dosing experiments have shown it to be highly toxic; however, the concentration that will be harmful when present in sewage reaching a works is unknown.

References

Chekhovskaya et al., 1966; Cherry, Gabaccia, and Senn 1956; Kunke, Hall, and Oeben, 1968; Ludzack, Schaffer, and Bloomhuff, 1961; Ludzack et al., 1959; Ministry of Technology, 1969a; Young, Ryckman and Buzzell, 1968.

Aniline†

Aniline is biodegradable during aerobic sewage treatment and is not very toxic except possibly to nitrifying bacteria. It does not appear to be metabolised during sludge digestion; its toxicity to this process is unknown but high toxicity is unlikely. In the circumstances the concentration acceptable at a sewage works would be determined by the amount of BOD loading that could be satisfactorily dealt with.

References

Gubser 1971; Oldham and Pearson, 1962; Tarvin and Buswell, 1934; Tomlinson, Boon, and Trotman, 1966; Wilson, 1954; Young, Ryckman, and Buzzell, 1968.

Benzene†

This solvent is biodegradable, though it is often necessary for the treatment process to be carefully acclimatized to the level discharged to ensure effective removal. It can be appreciably toxic, both to aerobic and anaerobic processes, and it is not destroyed during sludge digestion. It is difficult to suggest an acceptable level in a sewage effluent, as this is affected by the degree of acclimatization than can be achieved, but tentatively it would appear that up to 50 mg/l would normally not be harmful and that an order of magnitude higher could frequently be treatable under appropriate conditions.

References

Barash, 1955; Heukelekian and Schulhoff, 1940; Kumke, Conway, and Creagh, 1968; Kumke, Hall, and Oeben, 1968; Rudolfs, 1944; Tarvin and Buswell, 1934.

Benzoic acid

Benzoic acid is readily biodegraded; it is indeed an intermediate in the microbial breakdown of many aromatic compounds. It is equally readily destroyed during anaerobic sludge digestion and the level acceptable to a sewage works would therefore depend simply on the capacity of the works to treat it.

References

Kunke, Hall, and Oeben, 1968; Tarvin and Buswell, 1934; Young, Ryckman, and Buzzell, 1968.

Benzyl alcohol †

Benzyl alcohol is biodegradable and of low toxicity to sewage-treatment processes. It is at least slightly attacked during sludge digestion. As with other readily biodegradable compounds, the acceptable level will depend on the load that can be accepted by the particular treatment plant.

References

Hammerton, 1957; Marion and Malancy, 1963; Tarvin and Buswell, 1934.

BHC

[1,2,3,4,5,6-hexachlorocyclohexane; various isomers, of which the γ -isomer is the most biologically active when used as an insecticide, but other isomers may also be present in commercial materials. Also known as HCH, lindane (99 per cent γ -BHC), benzene hexachloride, and hexachloran (USSR).]

BHC is probably not degraded during sewage treatment; although a proportion may be adsorbed on sewage sludges, at least 50 per cent may appear in the effluent (WPKL, unpublished data). It is possible for the accumulation of γ -BHC on sludges to reach amounts toxic to digestion, but some destruction can occur, though the degradation products have not been identified and the metabolic changes may be slight. Toxicity to aerobic micro-organisms appears to be low but, as with other insecticides, the effect of BHC on predators is an important factor. There is, however, some evidence that nitrifying bacteria are harmed by low concentrations of γ -BHC, but the significance of this to sewage treatment is unknown. Acceptable levels for discharge of the insecticide to sewers would depend primarily on the need to protect surface waters, though some account would need to be taken of accumulation in sewage sludges.

References

Department of Scientific and Industrial Research, 1949; Eichelberger and Lichtenberg, 1971; Garretson and Clemente, 1968; Hill and McCarty, 1967; Leigh, 1969; Okey and Bogan, 1963; Philipp and Quentin, 1969; Raghu and MacRae, 1966.

Biphenyl (diphenyl)

Information on the behaviour of this chemical, which is used as a heat transfer agent or in organic syntheses, in sewage-treatment processes, is very sparse. It appears, however, that activated sludge can be acclimatized to break it down, but it may also be toxic, though the actual level at which toxicity occurs is not known. It also appears that some bacteria can metabolize it completely, and such bacteria have been found in soil and waste waters containing it. No information is available as to its behaviour during sludge digestion.

References

Catelani et al., 1970; Catelani, Sorlini, and Treccani, 1971; Lunt and Evans, 1970; Malaney and McKinney, 1966.

1-Butanol† (butyl alcohol)

A commonly used solvent, 1-butanol is readily biodegradable and of low toxicity to aerobic treatment processes. It can also be destroyed during the anaerobic treatment of sewage sludges, but there is some evidence that appreciable amounts can be inhibitory. It seems likely that the presence of a few hundred mg/l of the alcohol in sewage would normally be harmless.

References

Gerhold and Malaney, 1966; Hammerton, 1955; Kumke, Hall, and Oeben, 1968; Rudolfs, 1944; Symons and Buswell, 1933.

2-Butanone†
(methyl ethyl ketone)

Quite high concentrations of this solvent (up to 1000 mg/l), which is of low toxicity to aerobic processes, are treatable in acclimatized biological treatment plants, and the acceptable level in sewage treatment would therefore be determined by the load that could be dealt with by the particular plant. Although there is no information on this aspect, it is not expected that effects on the anaerobic digestion of sewage sludges would be of significance in practice.

References

Gerhold and Malaney, 1966; Ministry of Technology, 1965b; Young, Ryckman, and Buzzell, 1968.

Chlorobenzene†

In normal circumstances, chlorobenzene may be regarded as not treatable by aerobic biological processes. There is no evidence that processes can be acclimatized to break it down and this may be regarded as unproven, though it remains a possibility. Some accumulation on sewage sludges to levels toxic to sludge digestion may occur, but the acceptable concentration in the influent sewage of a works has not been ascertained. What little evidence there is suggests that harmful effects to aerobic processes will not occur below at least 10 mg/l, but whether or not this concentration would eventually affect the digestion of the sewage sludges is not known.

References

Okey and Bogan, 1963; Oldham and Pearson, 1962; Gubser, 1971; Swanwick and Foulkes, 1971.

Chlorocresols†

Chlorocresols are used as antiseptics and disinfectants. As far as can be ascertained, 4-chloro-m-cresol is the isomer most likely to occur in sewage or industrial waste waters, but 6-chloro-o-cresol appears

to be used as well. It is possible also that various isomers may occur as breakdown products of phenoxyalkanoic acid herbicides, for example MCPA. Information about these compounds is very sparse indeed and therefore no definite conclusion about them can be drawn. It does, however, seem likely that low concentrations could be biodegraded by acclimatized aerobic treatment processes. For removal of higher concentrations, biological treatment could be preceded by adsorption on activated charcoal.

Reference

Chambers, Tabak, and Kabler, 1963.

Chloroform†

This solvent is of most interest in the sewage-treatment field as a result of its very high toxicity to the anaerobic digestion of sewage sludges. In general it may be concluded that the concentration entering a sewage works would need to be limited to at least 0.1 mg/l in sewage, but there are many factors involved, among which the presence of other inhibitory compounds is of considerable importance. Fairly low concentrations may also affect aerobic processes, particularly nitrification. There is some evidence that chloroform is biodegradable.

References

Aleksandrova, Zhdanova, and Kollerova, 1962; Ministry of Technology, 1964; Heukelekian, 1947; Tomlinson, Boon, and Trotman, 1966; Swanwick and Foulkes, 1971.

o-, m-, p-Chlorophenol†

Monochlorophenols are difficult to degrade, but if suitable acclimatization can be carried out it is possible to destroy them, at least partially, at sewage works. In practice the concentration would need to be kept low to ensure effective removal and it is suggested that this should not exceed about 20 mg/l for the most efficient breakdown to occur. Effects on sludge digestion are unknown.

References

Bunch and Chambers, 1967; Ettinger and Ruchhoft, 1950; Gubser, 1971; Ingols, Gaffney, and Stevenson, 1966; Okey and Bogan, 1963; Oldham and Pearson, 1962; Wilson, 1954.

o-,m-,p-Cresol†

No great difficulty is usually experienced by sewage works in dealing with moderate amounts of cresols discharged to them. Destruction also occurs during the digestion of sewage sludges. Low concentrations (11-16 mg/l) seriously inhibit nitrification, but acclimatization to higher levels would probably occur in practice. The acceptable level for treatment would depend on the circumstances of the plant concerned.

References

Ashmore, Catchpole, and Cooper, 1967; Bunch and Chambers, 1967; Council for Scientific and Industrial Research, 1959; Ettinger and Ruchhoft, 1949; Pankhurst, 1959; Tomlinson, Doon, and Trotman, 1966; Wolmer, 1949.

Cyclohexanol†

This solvent can apparently be biodegraded after appropriate acclimatization; toxicity is presumably low. Information is non-existent about anaerobic digestion, but there is no reason to expect high toxicity to occur.

References

Chambers, Tabak, and Kabler, 1963; Meissner, 1954; Pitter and Kuzderková, 1971.

2,4-D

(2,4-dichlorophenoxyacetic acid; it is manufactured as the acid, as the sodium salt, as amine salts, or as esters.)

The herbicide 2,4-D is biodegradable and non-persistent in soil, so it would be expected that it could be destroyed in biological sewage-treatment plants, but in fact published information is somewhat equivocal, probably showing that in actual practice there is a need for careful, and

perhaps lengthy, acclimatization. It can also persist for relatively long periods in surface waters. No information is available as to whether or not 2,4-D and its salts and esters accumulate in sewage sludges, nor on its behaviour during anaerobic digestion of the sludges. Because its toxicity to micro-organisms is low, it seems unlikely that a limit on its concentration in wastes based on toxicity to treatment process would be necessary, although of course a limit to protect surface waters may need to be imposed.

References

Aly and Faust, 1964, 1965; Howe, 1965; Kearney and Kaufman, 1969; Okey and Bogan, 1963; Philipp and Mentin, 1969; Robson 1966, 1968; Schwartz, 1966.

DDT [1,1,1-trichloro-2,2-bis(4-chlorophenyl)ethane]

DDT is resistant to biodegradation, but some biological conversion to other compounds of similar structure, such as TDE [1,1-dichloro-2,2-bis(4-chlorophenyl)ethane] and 'DDE' [1,1-dichloro-2,2-bis(4-chlorophenyl)ethylene], is known to occur slowly in animals, plants and soil. Toxicity to most micro-organisms is low, but TDE is very toxic to Nitrobacter. In aerobic sewage treatment DDT may be partially converted to TDE (and perhaps other compounds) and also both it and TDE at least of its metabolites, are adsorbed by sewage sludges to a considerable extent; precise quantitative data are not available (WPRL, unpublished data). Laboratory tests of the treatment by the activated-sludge process of sewage containing DDT have also shown that a concentration of 89 mg/kg of DDT (including TDE) in activated-sludge did not prevent the production of a well-nitrified effluent with a BOD of less than 10 mg/l; DDT did not appear to be toxic to protozoa in these tests. Predatory organisms, particularly in percolating filters, may be killed by traces of DDT present in sewage, but there is little published information about this.

DDT adsorbed on sludges is converted via TDE to other compounds during anaerobic digestion, but these have not been identified. As with dieldrin (see below) accumulation in sludges and the occurrence in a sewage-works effluent of an appreciable proportion of the DDT (including metabolites) originally present in the influent sewage would make its absence from wastes desirable.

References

Department of the Environment, 1971; Eichelberger and Lichtenberg, 1971; Hill and McCarty, 1967; Okey and Bogan, 1963; Philipp and Quentin, 1969; Winely and Clemente, 1970.

Dichlobenil (2,6-dichlorobenzonitrile)

Dichlobenil, apart from its normal herbicidal use, is also used as an aquatic weed-killer (at concentrations of 3 mg/l or less in the United Kingdom). Residues in surface waters slowly decline, but it is not clear whether this is a result of complete metabolism or merely because of its conversion to 2,6-dichlorobenzoic acid. It seems fairly likely that the latter compound would be biodegradable, but the rate at which it would break down, either in soil or in water, is not known. No information is available about the fate of dichlobenil in sewage treatment and, with the present lack of knowledge, predictions are not possible.

References

Cope, McCraren, and Eller, 1969; Kearney and Kaufman, 1969; Valin, 1966.

o-Dichlorobenzene ('orthodichlorobenzene')

This solvent appears to be resistant to biodegradation, but there is too little information to be certain of this and it is possible that suitable, if perhaps lengthy, acclimatization of an aerobic sewage-treatment process might result in its breakdown. Between 40- and 95-per cent removal has been

reported during activated-sludge treatment. Since attempts at acclimatization made no significant difference to the amount of removal, it seems likely that this resulted largely from adsorption of the sludge or perhaps stripping in the stream of air. Low concentrations (about 50 mg/l) are apparently not toxic. Sludge digestion is affected by the presence of appreciable amounts of o-dichlorobenzene, but the tolerable level in sewage has not been ascertained. A limit of about 5 mg/l in sewage could be hazarded, but the effect of this amount on digestion, if it were continuously present, would need to be watched.

References

Gubser, 1969, 1971; Oldham and Pearson, 1962; Swanwick and Foulkes, 1971.

1,2-Dichloroethane (ethylene dichloride, ethylene chloride)

There is only a little information available about this solvent, which suggests it is not degradable in sewage treatment. However, it is not known if a process would eventually acclimatize to its breakdown. The solvent accumulates on sludges, and low concentrations have been found to cause inhibition of sludge digestion (tests were made at the low temperature of 21°C): data are inadequate to predict toxic concentrations in the sewage influent to a works, but concentrations would no doubt have to be low.

References

Lamb and Jenkins, 1952, Mills and Stack, 1953; Rudolfs, 1944.

Dichlorophen [2,2-methylenedi(4-chlorophenol), bis(5-chloro-2-hydroxyphenyl)methane]

It seems unlikely that dichlorophen, a fungicide and pharmaceutical product, would be readily degradable during sewage treatment. It has been shown to have no effect on the activated-sludge process at 0.1 mg/l, while 1 mg/l was initially toxic to nitrification. Some adsorption (about 50 per cent) occurs on primary sludge, and the limit for inhibition of sludge digestion is 1 mg/l in the sewage.

Reference

Ministry of Technology, 1965a.

2,4-Dichlorophenol†

This compound is biodegradable, though a period of acclimatization may be required before efficient removal is achieved during sewage treatment. It may be toxic to unacclimatized systems. It is difficult to suggest an acceptable level for sewage treatment but something of the order of 20 mg/l seems reasonable on the inadequate evidence. Such levels would probably not affect sludge digestion, but there is a complete absence of data on this aspect.

References

Bunch and Chambers, 1967; Gubser, 1971; Ingols, Gaffney, and Stevenson, 1966; Wilson, 1954.

Dieldrin

Aldrin may be included under this heading as it is biologically converted to dieldrin by epoxidation in plants, animals, and micro-organisms. Both insecticides appear to be of fairly low toxicity to micro-organisms, but they may be highly toxic to predatory organisms, particularly in percolating filters. Dieldrin is highly resistant to biodegradation and destruction during sewage treatment is negligible. Considerable removal of dieldrin on sewage solids has been reported to occur; nevertheless appreciable amounts will appear in a sewage-works effluent and the acceptable level will depend on this as well as on the accumulation of the insecticide in sewage sludges. Destruction of dieldrin during sludge digestion would also seem to be negligible. In the circumstances its complete absence from wastes would appear to be a desirable aim (c.f. DDT).

Laboratory tests on the effect of dieldrin on the activated-sludge process showed that concentrations of 125 mg/kg of dieldrin in activated sludge in the mixed liquor did not prevent the production of well-nitrified effluent with a BOD less than 10 mg/l; at this concentration the insecticide did not appear to be toxic to protozoa.

References

Department of the Environment, 1971; Eichelberger and Lichtenberg, 1971; Hill and McCarty, 1967; Okey and Bogan, 1963; Philipp and Quentin, 1969.

Diethylene Glycol†

Diethylene glycol appears to be rather difficult to degrade biologically in sewage treatment, even with acclimatization, and in the only reports where biodegradation was achieved, only slow breakdown occurred. It appears to be of low toxicity. Bacteria have been isolated from soil able to utilize the compound however, and anaerobic degradation after prolonged acclimatization has also been reported. More thorough investigation seems to be necessary before accurate conclusions can be drawn about this compound.

References

Gerhold and Malaney, 1966; Hatfield, 1957; Mayberry, Prochazka, and Payne, 1967; Mills and Stack, 1954; Young, Ryckman, and Buzzell, 1968.

Dimethylformamide†

This very versatile solvent can be treated by the activated-sludge process at moderate concentrations after a long period of acclimatization. A limit of about 20 mg/l appears to be reasonable on present evidence; this amount in sewage would not affect digestion of primary sludges (MPRL, unpublished data). However, much higher amounts have been reported to be biologically treatable under special conditions:

References

Arenshtein, Dmitrieva, and Svitsyna, 1962; Chudoba, Pitter, and Madera, 1969; Guber, 1969, 1971.

Dicunt
(9,10-dihydro-8a,10a-diazoniaphenanthrene ion; 1,1'-ethylene-2,2'-
bipyridylium ion; usually supplied as the dibromide)

This herbicide may be used in water (at 2 mg/l or less in the United Kingdom). It is rapidly lost by adsorption on sediment in natural waters and subsequently persists for a long time though inactivated. There are no specific data on its fate during sewage treatment, but it seems a reasonable assumption that it would be strongly adsorbed by anionic materials in sludges and thereby removed, and that its toxicity would be insignificant.

References

Funderburk and Bozarth, 1967; Grzenda, Nicholson, and Cox, 1966.

Ethanol (ethyl alcohol)

Ethanol is readily biodegradable and of low toxicity to both aerobic and anaerobic sewage-treatment processes; it is also destroyed anaerobically. The acceptable concentration at a sewage works would be determined by the BOD loading that could be dealt with by the particular plant.

References

Gerhold and Malaney, 1966; Kunke, Hall, and Oeben, 1968; Oldham and Pearson, 1962; Rudolfs, 1944; Symons and Buswell, 1933; Tomlinson, Boon, and Trotman, 1966; Young, Ryckman, and Buzzell, 1968.

2-Ethoxyethanol† (ethylene glycol monoethyl ether)

A widely used solvent, 2-ethoxyethanol is readily assimilated during aerobic sewage treatment, and is of low toxicity. There are no data about its behaviour during sludge digestion, but it is a fair assumption that its toxicity would be slight and that it would be metabolized. The amount treatable would depend on the plant capacity.

References

Bogan and Sawyer, 1955; Mills and Stack, 1953; Pitter, 1968.

Ethylenediamine†

Ethylenediamine, which is used as a solvent and a stabilizer, is biodegradable after acclimatization, but there is no information available about toxic levels. It would seem that 50 mg/l would be acceptable. Its behaviour in sludge digestion is uncertain, but presumably it would react with anionic materials and not be harmful.

References

Lyon, 1950; Mills and Stack, 1954.

Ethylenediaminetetraacetic Acid

Present evidence suggests that EDTA is resistant to biodegradation and has no appreciable toxicity to sewage-treatment processes, but there may be some physical effects on settlement of sludges at low concentrations. However, the main problem with strong chelating agents of this kind is the carrying through of toxic metals into sewage effluents, which may be undesirable although it reduces their immediate toxicity. It seems improbable that there would be appreciable adsorption of EDTA on sewage substances, by analogy with nitrilotriacetic acid. It is not possible at present to suggest an acceptable concentration for discharges to sewers, but it is obviously desirable to keep the quantities discharged to as low a level as practicable.

References

Bunch and Ettinger, 1967; Potos, 1965; Tomlinson, Boon, and Trotman, 1966.

Ethylene Glycol† (1,2-ethanediol)

Ethylene glycol is readily biodegradable and of low toxicity to aerobic processes. It is also metabolized during the anaerobic sludge digestion process. As with other biodegradable chemicals the concentration that can be accepted at a sewage works would be determined by the capacity of the plant concerned.

References

Gerhold and Malaney, 1966; Oldham and Pearson, 1962; Symons and Buswell, 1933; Young, Lyckman, and Buzzell, 1968.

Formaldehyde†

Formaldehyde may be treated at quite high concentrations after suitable acclimatization, but for the most efficient destruction under normal conditions, concentrations need to be kept to moderate levels, say about 100 mg/l. Shock doses can be very toxic. There is some evidence that sludge digestion can be affected by formaldehyde, but this is inadequate to predict tolerable levels in the sewage influent.

References

Dickerson, Campbell, and Stankard, 1954; Gilcreas, 1946; Ministry of Technology, 1968; Strong and Hatfield, 1954; Waldmeyer, 1952.

Formic Acid†

Formic acid is readily biodegradable and is easily destroyed in both aerobic and anaerobic treatment processes; in the case of the latter, in particular, control of pH may be necessary. The acceptable level for sewage treatment would depend on the plant capacity.

References

Gerhold and Malaney, 1966; Keefer and Urtes, 1963; Mills and Stack, 1953; Symons and Buswell, 1933.

Hexachlorophene

[6,6'-methylenebis(2,4,5-trichlorophenol), bis(2-hydroxy-3,5,6-trichlorophenyl)methane, hexachlorophene]

A widely used germicide and disinfectant, hexachlorophene is known to be highly toxic to sludge digestion when present in sewage. It is not known what level would prove toxic to aerobic processes, nor is there any specific information about its biodegradability. It seems reasonable to suppose that it would be resistant to complete breakdown; and in view of

this and its high toxicity to sludge digestion, a severe restriction on its concentration in sewage is likely.

Reference

Summers, 1966.

Hexamethylenetetramine† (hexamine, methenamine)

Hexamine, which has many uses such as in the vulcanization of rubber, medicine, and chemical manufacture, is of low toxicity but if it is biodegradable at all it is degradable only after a long period of acclimatization of the micro-organisms in aerobic processes. Its behaviour in sludge digestion is not known.

References

Hermann, 1959; Heukelekian, 1950; Swope and Kenna, 1950.

Maleic Acid/Maleic Anhydride†

These compounds are used in chemical manufacturing; the anhydride is hydrolysed to the acid in water. Maleic acid is biodegradable and not particularly toxic to aerobic processes. Some acclimatization may be necessary for the most efficient treatment to occur. There is no reason to suppose that toxicity to sludge digestion would be significant and the acceptable concentration in sewage would therefore be determined by the capacity of the particular sewage works.

References

Heukelekian and Rand, 1955; Malaney and Gerhold, 1969; Swope and Kenna, 1950; Wilson, 1954; Young, Ryckman, and Buzzell, 1968.

2-Mercaptobenzothiazole

This compound, which is used in the vulcanization of rubber, is highly toxic to nitrifying bacteria in the activated-sludge process; it may also be toxic to the other organisms at low concentrations, though there is no information about this. There is some evidence that acclimatization

to the compound can occur, but it seems to be largely resistant to breakdown. A limit of a few mg/l would seem to be desirable for intermittent discharges, but it might be possible to increase this if acclimatization can be achieved, though it is doubtful if it would be substantially removed. Effects on sludge digestion are not known.

References

Tomlinson, Boon, and Trotman, 1966; Wilson, 1954.

Methanol†

Methanol is readily destroyed during sewage treatment, though acclimatization to the expected levels is often necessary for efficient removal to occur. The limit treatable would be determined by the load acceptable to the particular plant. It is also metabolized during sludge digestion, though appreciable amounts present in a digester may cause initial toxicity.

References

Gerhold and Malaney, 1966; Kunake, Hall, and Oeben, 1968; Rudolfs, 1944; Symons and Buswell, 1933; Waldmeyer, 1952; Young, Ryckman and Buzzell, 1968.

Methylene Bisthiocyanate

This industrial microbiocide is highly toxic to both aerobic and anaerobic sewage-treatment processes and it would appear on limited evidence that concentrations above about 0.5 mg/l would be harmful; some degradation to release thiocyanate also occurs. The possibility of treatment processes acclimatizing to the compound in the long-term has not yet been investigated.

Reference

Brown, Kitchin, and Harmston, 1971.

Methylene Chloride†

Methylene chloride is not very toxic to aerobic processes and there is evidence that it is biodegradable. However, the solvent has a very high toxicity to sludge digestion, which causes it to be regarded as an undesirable constituent of industrial wastes at sewage works, and concentrations of 1 mg/l or more in the sewage influent are harmful.

References

Aleksandrova, Zhdanova, and Kollerova, 1962; Tugarinova et al., 1965; Ministry of Technology, 1964.

Methyl Methacrylate

The monomer of Perspex, methyl methacrylate appears to be biodegradable and of low toxicity in aerobic biological processes. It is difficult to express an opinion about its effect on sludge digestion with any degree of certainty, but it seems unlikely to be a problem.

References

Pahren and Bloodgood, 1961; Stack, 1957.

4-Methyl-2-pentanone† (methyl isobutyl ketone, isopropylacetone)

A fairly common solvent, this compound is apparently biodegradable, but some acclimatization is necessary. It is not highly toxic to aerobic processes, and this is probably also true of anaerobic digestion* although there are no published data about it.

References

Gerhold and Kalaney, 1966; Lyon, 1950; Mills and Stack, 1953.

Morpholine†

A useful industrial chemical, morpholine is difficult to degrade biologically, but biodegradation can apparently be achieved after a prolonged period of acclimatization. Toxicity to aerobic processes is low, but nothing is known about its effect on sludge digestion. It would

appear to be desirable to keep concentrations in sewage to fairly low levels.

References

Lamb and Jenkins, 1952, Mills and Stack, 1953, 1955; Swope and Kenna, 1950.

Nitrobenzene

Although generally resistant to breakdown and appreciably toxic, low concentrations of nitrobenzene (about 30 mg/l) may be treated by an acclimatized activated-sludge plant (MPRL, unpublished data). Nothing is known about its effect on sludge digestion.

References

Chambers, Tabak, and Kabler, 1963; Marion and Malaney, 1963.

Oxalic Acid

Oxalic acid and oxalates are biodegradable, though acclimatization may be necessary. These are of fairly low toxicity to aerobic processes and are also destroyed during anaerobic digestion. There is, however, evidence that high concentrations can cause accumulation on sludges to an extent that inhibits digestion, but precise conclusions are not possible. Amounts of 50-100 mg/l in sewage may be tentatively regarded as tolerable.

References

Bell and Jones, 1965; Malaney and Gerhold, 1969; Nelson, Reading, and Christenson, 1954; Symons and Buswell, 1933; Young, Ryckman, and Buzzell, 1968.

Pentachlorophenol†

This fungicide is highly resistant to breakdown and, except under exceptional circumstances, is virtually untreatable biologically. Furthermore it accumulates on sewage sludges and a concentration as low as 0.4 mg/l in the influent sewage has been reported to be the toxic limit for the anaerobic digestion of sewage sludges. The discharge of pentachlorophenol

to sewers and surface waters therefore requires strict control. Derivatives of pentachlorophenol, e.g. pentachlorophenyl laurate, are at least rather less toxic, but, since they release the phenol slowly with time, they should be regarded in the same way as the free phenol.

References

Drew and Swanwick, 1963; Heidman, Kincannon, and Gaudy, 1967; Ingols, Gaffney, and Stevenson, 1966; Ministry of Technology, 1965a; Sidwell, 1971.

Phenol†

(this name is used here to mean the pure chemical, C_6H_5OH ; for other 'phenols' see under "Cresol" and "Xylenols" and various substituted phenols.)

The amount of phenol that can be destroyed aerobically during sewage treatment varies according to the particular circumstances of the plant. Under appropriate conditions as much as 2000 mg/l of phenol can be efficiently treated but, in general, given a reasonable time for acclimatization, concentrations of about 50-200 mg/l can be regarded as the practical limit. Low concentrations can inhibit nitrification, but although information is lacking on this aspect it is to be expected that acclimatization would occur. Phenol does not normally affect sludge digestion; indeed considerable amounts can be destroyed in the process after acclimatization.

References

Ashmore, Catchpole, and Cooper 1967; Bunch and Chambers, 1967; Council for Scientific and Industrial Research, 1959; Lesperance, 1961; Meissner, 1953, 1955; Schönborn and Beyer, 1966; Tarvin and Buswell, 1934; Tomlinson, Boon, and Trotman, 1966; Wilson, 1954.

o-Phenylphenol†

This fungicide, which is also available as the sodium salt ('sodium orthophenylphenate'), is somewhat toxic to aerobic processes, but might be treatable after acclimatization at low concentrations. However, information is sparse and conclusions remain uncertain.

References

Chambers, Tabak, and Kabler, 1963; Oldham and Pearson, 1962; Wilson, 1954.

Phthalic Anhydride†

Phthalic anhydride, a compound of considerable technical importance in the synthesis of other organic compounds, is readily biodegradable. It is also destroyed during sludge digestion. The acceptable concentration for sewage treatment is probably simply dependent on plant capacity.

References

Chambers, Tabak, and Kabler, 1963; Heukelekian and Rand, 1955; Pitter and Kozderková, 1971; Tarvin and Buswell, 1934; Wilson, 1954.

2-Propanol† (isopropyl alcohol)

A widely used solvent, 2-propanol is of low toxicity to aerobic sewage-treatment processes and may be readily destroyed after acclimatization. Concentrations of 100 mg/l or so should be easily dealt with. There is no information available on its effect on sludge digestion, but there is no reason to suppose that it will normally be of significant toxicity.

References

Gerhold and Malaney, 1966; Hammerton, 1957; Kumke, Hall, and Oeben, 1968; Young, Ryckman, and Buzzell, 1968.

Pyridine†

Pyridine is rather resistant to biodegradation during sewage treatment, but with prolonged acclimatization it can be destroyed. It does not seem to be appreciably toxic to aerobic processes, there are no data about its effect on sludge digestion.

References

Ettinger, Lishka and Kroner, 1954; Gerhold, 1962; Grünwald, 1968; Gubser, 1969, 1971; Young, Ryckman, and Buzzell, 1968.

Quinol
(hydroquinone)

This compound, which is used in photography, is biodegradable; some acclimatization may be necessary, as it can be fairly toxic. It is apparently also destroyed during anaerobic digestion after acclimatization. Comparable concentrations can be dealt with in a similar way to phenol.

References

Chambers, Tabak, and Kabler, 1963; Weissner, 1953; Young, Ryckman, and Buzzell, 1968.

Styrene

Styrene, which is an important compound in the manufacture of plastics etc, is treatable by aerobic processes at low concentrations; information is inadequate to suggest an acceptable level. It is toxic to sludge digestion at moderate levels (above 200 mg/l in the digester contents).

References

City of Bristol, 1968; Harkness and Jenkins, 1958; Kunke, Hall, and Ooben, 1968; Mills, 1969; Ministry of Technology, 1969b; Pahren and Bloodgood, 1961.

2,4,5-T
(2,4,5-trichlorophenoxyacetic acid; used as salts or esters)

Although regarded as much more persistent in soil than 2,4-D, this herbicide appears to be biodegradable during sewage treatment to at least some extent. High concentrations are toxic, but this would be of little practical significance normally. Its effect on sludge digestion is unknown; it seems unlikely to be of appreciable toxicity.

References

Kearney and Kaufman, 1969; Okey and Bogan, 1963; Philipp and Quentin, 1969.

Tetrachloroethylene
(perchloroethylene)

An important solvent, tetrachloroethylene is probably not easy to treat aerobically, though it is not of high toxicity. However, low concentrations present in sewage will inhibit sludge digestion. Information is inadequate to predict the precise safe levels in sewage, but it is tentatively suggested that 2 mg/l would be tolerated in the absence of other inhibitors.

References

Oldham and Pearson, 1962; Swanwick and Foulkes, 1971.

Toluene†

Toluene is biodegradable and apparently not very toxic to aerobic treatment processes, though there is some indication of toxicity to nitrifying bacteria. However, it is not possible on the available information to suggest acceptable levels. Toluene is also somewhat toxic to the anaerobic digestion process and is not metabolized.

References

Barash, 1955; Kunke, Hall, and Oeben, 1968; Rudolfs, 1944; Tarvin and Buswell, 1934; Young, Ryckman, and Buzzell, 1968.

p-Toluenesulphonic Acid†

A dye chemical, p-toluenesulphonic acid is biodegradable during sewage treatment, though acclimatization may be necessary for efficient removal. There is no information about its toxicity to sludge digestion, but it seems reasonable to suppose that this would not be an important consideration in practice.

References

Cain and Farr, 1968; Pittor, 1968; Sawyer and Ryckman, 1957; Symons and Valle-Rivera, 1961.

1,1,1,Trichloroethane
(methylchloroform)

No information is available on the biodegradability and toxicity of this solvent in aerobic biological treatment processes. It is doubtful whether it would be seriously toxic and it is possible that it might be broken down after acclimatization. It is, however, extremely toxic to the anaerobic digestion of sewage sludges and for this reason its concentration in sewage needs to be controlled. On present evidence the toxic limit would be below 0.1 mg/l.

Reference

Swanwick and Foulkes, 1971.

Trichloroethylene
(unstable in light; commercial grades may contain stabilizers)

This solvent is not very toxic to aerobic treatment processes. The little information available suggests it is not biodegradable, but it is not known whether or not acclimatization can occur. Though not as highly toxic as 1,1,1-trichloroethane, trichloroethylene is still very toxic to anaerobic digestion and the toxic limit might be tentatively taken to be about 1 or 2 mg/l in the influent sewage, though information is inadequate for an accurate estimate to be made.

References

Oldham and Pearson, 1962; Swanwick and Foulkes, 1971.

Trichlorophenols
(6 isomers of this compound exist; the more important ones
are the 2,4,5- and 2,4,6-isomers)

2,4,5- and 2,4,6-trichlorophenol are important bactericides and fungicides, and so are probably toxic to aerobic treatment processes at fairly low concentrations. Inhibition to BOD by the 2,4,6-isomer occurs above 50 mg/l. Complete breakdown of this isomer has been achieved by the activated-sludge process after prolonged acclimatization; information is lacking about the others.

It is possible that accumulation on sewage sludges would occur with subsequent inhibition of anaerobic digestion, but there is no information about this. It is therefore impossible to suggest acceptable levels for sewage treatment.

References

Chambers, Tabak, and Kabler, 1963; Ingols, Gaffney, and Stevenson, 1963; Okey and Bogan, 1963; Oldham and Pearson, 1962.

Triethanolamine†

It is apparent from the limited information available that triethanolamine, a compound widely used in the manufacture of synthetic chemicals, might be biodegradable after suitable acclimatization. Toxicity is probably slight. Serious effects on sludge digestion are unlikely, but no data are available. Under normal circumstances a concentration of 50 mg/l in sewage should be acceptable.

References

Heukelekian and Rand, 1955; Lyon, 1950; Mills and Stack, 1953, 1954.

Triethylamine†

Triethylamine, which is used in the manufacture of quaternary ammonium compounds, is apparently difficult to treat biologically; it may also be somewhat toxic. Its behaviour in sludge digestion is unknown.

References

Aleksandrova, Zhdanova, and Kollerova, 1962; Chudoba, Pitter, and Madera, 1969.

Triethylene Glycol†

Triethylene glycol appears to be difficult to degrade but there is some slight evidence that some biodegradation, at least, might occur after acclimatization. Toxicity seems to be low. The glycol is destroyed anaerobically after acclimatization.

References

Gerhold and Kalanay, 1966; Hatfield, 1957; Mayberry, Prochazka, and Payno, 1967; Mills and Stack, 1953, 1954.

o-,m-,p-Xylenes†

(commercial xylene is predominantly m-xylene, but all three isomers are present)

Xylenes, which apart from their use as solvents are important in the production of many synthetic chemicals, are probably rather difficult to degrade during sewage treatment; toxicity is probably not very great. m-Xylene is appreciably toxic to sludge digestion (at 21°C); the amount in sewage which would affect digestion is, however, not known.

References

Kalanay and McKinney, 1966; Rudolfs, 1944.

Xylenols†

[six isomers exist: 2,3-, 2,4-, 2,5-, 2,6-, 3,4-, and 3,5-xylenol; 'xylenol' is synonymous with 'dimethylphenol' in the IUPAC nomenclature. Beilstein's nomenclature (vic-o-xylenol, etc) is now not often used and may be most conveniently referred to in the Merck Index (1968) p.1122]

Although micro-organisms capable of utilizing all 6 isomers of xylenol have been isolated from activated sludge treating carbonization waste liquor and from various other sources, for a few isomers, xylenols are rather resistant to biodegradation in sewage treatment. However, it seems that with careful acclimatization, breakdown can be achieved. Information on toxic levels is slight and unsatisfactory, but it appears that xylenols can be toxic to nitrification. It would therefore be sensible to keep their total concentrations in sewage to quite low levels, say 5-10 mg/l, but this can be only a tentative suggestion.

References

Chambers, Tabak, and Kabler, 1963; Kaplin, Semenchenko, and Ivanov, 1968; McKinney, Tomlinson, and Wilcox, 1956; Weissner, 1953; Ministry of Technology, 1969c.

5. SURFACTANTS

The classes considered, which are believed to be those most important commercially, have been classified as follows in Table 1:

- Very soft (vs). Virtually complete removal to be expected by efficient sewage works at all ambient temperatures.
- Soft (s). More than 90 per cent removal.
- Hard (h). Less than 90 per cent removal.
- Very hard (vh). Removal insignificant (less than about 20 per cent).

Note: references have not been provided for this section; however, a review of this subject has been published by Swisher, R. D. (Surfactant biodegradation, Marcel Dekker, New York, 1970, 496 pp.).

Table 1. Surfactant biodegradability

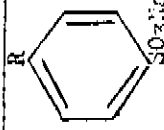
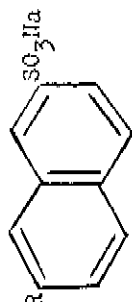
Class of substance	Structural formulae	Alternative descriptions	Biodegradability	Notes
Alkylbenzenesulphonates, branched	 <p>R = branched alkyl groups</p>	ABS	h or vh	Unlikely to be toxic to aerobic processes at concentrations normally present in sewage, but can accumulate in sludges and will be inhibitory to sludge digestion at above about 2 per cent on dry solids basis
Alkylbenzenesulphonates, linear	as above; but R = substantially unbranched groups	LAS (= 'linear alkylate sulphonate')	s	
Alkylnaphthalenesulphonates			h or vh	
Alkyl sulphates	ROSO ₃ Na	alcohol sulphates	(vs (linear, primary) (s (some secondary))	Not significantly toxic in practice
Alkyl sulphonates	RSO ₃ Na	alkane sulphonates	s	"
Ethoxylated aliphatic acids	RCOO(C ₂ H ₄ O) _n H	polyoxyethylene esters of fatty acids	s (some materials with high 'n' are hard)	"
Ethoxylated aliphatic alcohols†	R(CO ₂ H) _n OH	(polyoxyethylene alcohols, alcohol ethoxylates	usually s or vs	"

Table 1 (contd.)

Class of substance	Structural formulae	Alternative descriptions	Biodegradability	Notes
Ethoxylated alkylamines	$\text{HOCH}_2(\text{C}_2\text{H}_4\text{O})_n\text{H}$ $(n = 1 \text{ or } 2)$	{ polyoxyethylene { alkylamides, { fatty amide { ethoxylates, { ethanolamine { ethoxylates	usually s	"
Ethoxylated alkylamines	$\text{HO} \begin{array}{l} \diagup \\ \diagdown \end{array} \begin{array}{l} (\text{C}_2\text{H}_4\text{O})_n\text{H} \\ (\text{C}_2\text{H}_4\text{O})_n\text{H} \end{array}$	polyoxyethylene alkylamides	s	"
Ethoxylated alkylphenols	$\text{X} - \text{C}_6\text{H}_4 - (\text{OC}_2\text{H}_4)_n\text{OH}$ (o- and p-)	polyoxyethylene alkylphenols ethoxylates	s to vh vh at low ambient temperature; some may be soft at high temperatures	"
Ethoxylated alkyl sulphates	$\text{X}(\text{OC}_2\text{H}_4)_n\text{OSO}_3\text{Na}$	sulphated polyoxyethylene alcohols	s or vs (see alkyl sulphates; biodegradability also decreases with increase in 'n')	"
Quarternary ammonium compound	$\text{R}^1\text{R}^2\text{R}^3\text{R}^4\text{N}^+\text{X}^-$ (where x is usually Cl or Br)	(some) 'cationic detergents'	vh	Potentially very toxic; in practice 'neutralized' by anionic materials (e.g. anionic detergents, soaps, nitrate). Removal thereby may be virtually complete
Polyethylene oxides Polyethylene glycols	$\text{HO} \begin{array}{l} \diagup \\ \diagdown \end{array} \begin{array}{l} (\text{C}_2\text{H}_4\text{O})_n\text{H} \\ (\text{C}_2\text{H}_4\text{O})_n\text{H} \end{array}$	polyoxyethylenes 'PEG'	h	Rate of removal decreases as size of molecule increases; very short chain compounds would be soft. Not significantly toxic; can be a nuisance by stabilising foaming caused by other materials

6. BIBLIOGRAPHY

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