Types of Disinfectant

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Background

In food factories, the detergent stage is normally followed by a disinfecting stage. The detergent stage is required to remove all the soil, leaving a chemically clean surface. The disinfectant stage is used as an extra guarantee of cleanliness and to prevent recontamination in some cases. It does not compensate for a bad detergent stage or badly designed process or cleaning equipment.

Disinfection

The definition of disinfection taken from BS5283 (1986) states 'The destruction of microorganisms, but not usually bacterial spores. It does not necessarily kill all microorganisms but reduces them to a level acceptable for a defined purpose, for example a level which is harmful neither to health nor to the quality of perishable goods.' The acceptable level of microbial contamination on a surface or piece of equipment has to be determined; obviously, no pathogens should be found. (*See* **Spoilage**: Bacterial Spoilage; Molds in Spoilage; Yeasts in Spoilage.)

The state of sterility is defined as free from all living microorganisms. This is not achievable in the food factory by using acceptable chemicals ('acceptable' meaning safe for humans, plant materials and products).

Disinfectants are used after the detergent application in cleaning-in-place (CIP) operations where the term 'terminal sterilant' may be used. They are also used after hand cleaning. Equipment should be left in a soak bath until it is ready to be used, thus ensuring that it remains free from recontamination.

There are a wide range of disinfectants available. The choice of disinfectant depends on the user's requirements, the type of processing and cleaning equipment, the method of use, and, to some extent, the personal preference of the user.

Types of Disinfectant

Disinfectants can be split into two broad groups, oxidizing and nonoxidizing. Oxidizing disinfectants include the halogens, chlorine, iodine, bromine, and chlorine dioxide, and oxygen-releasing materials such as peracetic acid and hydrogen peroxide. Nonoxidizing disinfectants are as follows: quaternary ammonium compounds, amphoterics, biguanides, and acid anionics.

Physical and Chemical Properties

Oxidizing Disinfectants

Halogens Chlorine and iodine have been used as terminal disinfectants for many years. More recently, bromine and chlorine dioxide have been introduced.

Chlorine Chlorine was first used as a gas for fumigation in hospitals in 1791, but this application has one obvious drawback – chlorine gas is toxic. Active chlorine is available from two types of material:

1. Inorganic compounds containing hypochlorite ions either as a liquid, e.g., sodium hypochlorite (NaOCl), or as a powder, e.g., chlorinated trisodium phosphate

$$((Na_3PO_4.11H_2O)_4NaOCl, NaCl).$$

2. Powdered organic chlorine release agents, e.g., trichloroisocyanurate (Figure 1).

In solution, both types hydrolyze to produce hypochlorous acid and/or hypochlorite ions, depending on the pH.

$$\begin{array}{ccccc} \text{Acid} & & & & \text{Alkaline} \\ Cl_2 & \rightleftharpoons & HOCl & \rightleftharpoons & OCl^- \\ \text{Chlorine gas} & & \text{Hypochlorous acid} & & \text{Hypochlorite ion} \end{array}$$

In the food industry, sodium hypochlorite is used as a general-purpose disinfectant. It is most stable in a slightly alkaline solution, and it is for this reason that the concentrate is supplied stabilized with sodium hydrocide at a pH of up to 12. An in-use solution of between 50 and 300 p.p.m. will have a pH between 7 and 9. The optimum pH for disinfection is pH 5.0, but

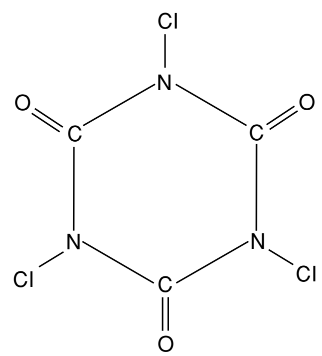


Figure 1 Trichloroisocyanuric acid. Reproduced from Cleaning Procedures in the Factory: Types of Disinfectant, *Encyclopaedia of Food Science, Food Technology and Nutrition*, Macrae R, Robinson RK and Sadler MJ (eds), 1993, Academic Press.

the solution is less stable. Below pH 5.0, chlorine gas will be produced.

Applications for sodium hypochlorite in the food industries are CIP, soak, and spray. Sodium hypochlorite has many advantages: it is nonfoaming; it is not affected by water hardness; it does not leave an active residue, and it has a wide antimicrobial spectrum, which includes activity against bacterial spores and viruses. It is also fast-acting and cheap.

However, it also has numerous disadvantages: it can be corrosive to a wide range of components, including stainless steel; it is irritating to the skin and eyes; the in-use solution is unstable; it is inactivated by organic materials, and it may give rise to taint problems.

Chlorine dioxide Chlorine dioxide (ClO_2) is an unstable and toxic gas that is soluble in water. When chlorine dioxide is generated in solution, as shown below, it is a very effective water disinfectant at point of use.

$$5NaClO_2 + 4HCl \rightleftharpoons 4ClO_2 + 5NaCl + 2H_2O.$$

Chlorine dioxide at use concentrations (0.5–1 p.p.m.) overcomes some of the disadvantages of hypochlorite in that it is nontainting, noncorrosive, and nontoxic. Its sole use at present is in water disinfection.

Iodine Iodine itself is not very soluble in water, and the vapor is irritating to the eyes, making it difficult to handle. Iodine is a very reactive element, and it is this reactivity that makes it a good disinfectant.

Iodine compounds used in the food industry contain iodine complexed with polyvinylpyrrolidone and other surface active agents, usually in an acid solution. These are known as iodophors and were first introduced in 1949.

The complexes formed between iodine and carrier molecule are water-soluble and overcome the handling difficulties of iodine whilst retaining the disinfecting power. On dilution, the iodophors release iodine gradually, and it is the free iodine that acts as the disinfecting agent. The optimum pH for microbial activity is pH 5.0.

$$\underset{\substack{\text{Greatest}\\ \text{activity}}}{\overset{\text{Acid}}{I_2}} \rightleftharpoons \underset{\substack{\text{Some}\\ \text{activity}}}{HOI} \rightleftharpoons \underset{\text{Inactive}}{OI^-} \rightleftharpoons \underset{\text{Inactive}}{\overset{\text{Alkaline}}{IO^-}}.$$

The surface-active agents provide better wetting and organic soil penetration, thus making iodophors less affected by soil than hypochlorite. The choice of surface-active agent may lead to foam generation in applications such as CIP.

Iodophors have a broad antimicrobial spectrum that is similar to hypochlorite, although they are less active against bacterial spores. In common with sodium hypochlorite, they are fast-acting but are more expensive. Iodophors are used in soak baths and spray application at up to 10 p.p.m. available iodine. In solution, iodophors are yellow-brown in color. This color can be an advantage: in a soak bath application, the color indicates the presence of iodine; the in-use solutions are unstable, so that as the iodine dissipates, the solution will become colorless.

Staining may be a problem, especially with some plastics, and this may also result in taint problems. Iodophors can be corrosive; it is therefore necessary to ensure that the correct dilution is used; otherwise, damage to plant and personnel may occur.

Bromine Bromine itself is not used as a disinfectant, mainly because of its handling difficulties. Bromochlorodimethylhydantoin is supplied as a powder or a solid. In solution, it releases hypobromous and hypochlorous acids.

Oxygen-releasing compounds

Peracetic acid Peracetic acid was introduced in 1955. The material is supplied as an equilibrium mixture:

$$\underset{\text{Peracetic acid}}{CH_3C(=O)OOH} + \underset{\text{Water}}{H_2O} \rightleftharpoons \underset{\text{Acetic acid}}{CH_3C(=O)OH} + \underset{\text{Hydrogen peroxide}}{H_2O_2}.$$

It is soluble in water and is completely biodegradable, breaking down to harmless products:

$$2CH_3C(=O)OOH \rightarrow 2CH_3C(=O)OH + O_2$$

As supplied, peracetic acid is corrosive and has a very irritating smell, similar to vinegar; because of these properties, it is unpleasant to handle, and manual use is not recommended. It is suitable for CIP, as it is nonfoaming.

Peracetic acid is a highly reactive material. As an in-use solution, it is not very stable and will react with organic materials. Peracetic acid may attack plant materials, such as rubber gaskets, and at higher concentrations, corrosion may be a problem.

Peracetic acid has a wide antimicrobial spectrum, which includes bacterial spores and viruses. This activity is fast and is maintained at temperatures lower than ambient.

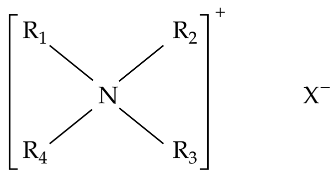
Hydrogen peroxide Hydrogen peroxide (H_2O_2) was introduced as a disinfectant in 1887. It is supplied in solution, which has a tendency to decompose:

$$2H_2O_2 \rightarrow 2H_2O + O_2.$$

Manual use of hydrogen peroxide is not recommended, but it is used in spray applications such as aseptic packaging. Hydrogen peroxide is both bactericidal and fungicidal. Some bacteria and fungi are less sensitive because of catalase activity, which destroys H_2O_2. Hydrogen peroxide is slow-acting, so that a long contact time or elevated temperature is required for effective disinfection.

Nonoxidizing Disinfectants

Quaternary ammonium compounds Quaternary ammonium compounds (QACs) were first introduced in 1917 and are probably the best known cationic surface-active agents. Their general formula is as follows:



X is usually a halide but sometimes a sulfate ion. R_1, R_2, R_3, and R_4 may be a variety of alkyl or aryl groups.

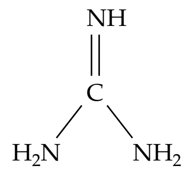
QACs are generally poor detergents but good wetting agents. In solution, they ionize to produce a cation, the substituted nitrogen part of the molecule, which provides the surface-active property. The length of the carbon chain in the R groups affects the disinfectant ability; usually, C_8 to C_{18} are the most effective.

The surface-active nature of these molecules tends to make them too high-foaming for CIP use, but they can be used for soak and manual cleaning at 200–400 p.p.m. active. The optimum activity is around neutral pH, but QACs are active between pH 3.0 and 10.0. Activity may be inhibited by water hardness.

QACs are noncorrosive and are stable at in-use dilution. Their major disadvantages are that they are affected by organic soil and that they tend to cling to surfaces, so that they may be difficult to rinse off, resulting in possible taint problems.

The antimicrobial range of QACs is less than that of the oxidizing disinfectants. They are less effective against Gram-negative bacteria than against Gram-positive bacteria. They also have limited activity against bacterial spores and very little activity against viruses. To be effective against yeasts and molds, a higher concentration is required.

Biguanides Biguanides with antimicrobial activity were first reported in 1933. The biguanides are derivatives of guanidine, a naturally occurring substance found in vegetables such as turnips and cereals:



Biguanides are usually supplied as polymers in the salt form, mostly as the hydrochloride. Optimum activity lies between pH 3.0 and pH 9.0. Below pH 3.0, activity is suppressed, whilst above pH 9.0, they are precipitated.

They are cationic in nature but are not regarded as surface-active. Biguanides do not foam and are, therefore, suitable for CIP; they may also be used for soak and manual cleaning. They are noncorrosive but taint may be a problem if not properly rinsed. The in-use solution is stable but is affected by organic soil and, to some extent, by hard water.

Most biguanides have equal antibacterial activity against Gram-positive and Gram-negative microorganisms. They are less effective against molds and yeasts, and are ineffective against bacterial spores and viruses.

Amphoterics Amphoterics have been in use as disinfectants since the early 1950s. They are based on a substituted amino acid, usually glycerine. The term ampholyte is often used to describe them because in solution they ionize to produce cations, anions, or zwitterions, depending on the pH:

$$R-\overset{+}{N}H_2-CH_2-CH_2-C(=O)OH$$
Acid cation

$$R-\overset{+}{N}H_2-CH_2-CH_2-C(=O)O^-$$
Zwitterion

$$R-NH-CH_2-CH_2-C(=O)O^-$$
Alkaline anion.

Only certain amphoterics have a disinfecting ability and surface activity. The disinfecting ability appears to increase with the increase of basic groups.

Amphoterics tend to be viscous liquids that are freely soluble in water. They are generally too high-foaming for use in CIP, but are suitable for soak, spray, and hand use. Amphoterics are equally effective against Gram-negative and Gram-positive bacteria; they are less effective against yeasts and molds, and have very little effect against bacterial spores and viruses. The optimum activity lies between pH 3.0 and 9.0.

Properties such as soil tolerance and corrosion vary with the amphoteric concerned. Corrosion is not usually a problem. The in-use solution, usually 1000 p.p.m. active, is stable.

Acid anionics The active molecule in acid anionics varies considerably. There are two main types: those based on carboxylic acids, which include fatty acids and derivatives, and those based on anionic surfactants combined with mineral acid.

Acid anionics tend to be formulated products with additions to aid activity or solubility. Properties will vary with product, but they tend to have some detergent and wetting ability. The higher-foaming products are unsuitable for CIP, so that their general use is for spray. They are not suitable for hand use, since a pH of 2 is required for optimum antimicrobial activity.

The antimicrobial activity is against Gram-negative and Gram-positive bacteria, but they are less effective against bacterial spores and viruses. Certain carboxylic acid types are active against yeasts and molds. Both types are affected by organic soil and water hardness, but again, both properties will vary with the product. The in-use solutions are stable.

Effluent Problems

The oxidizing disinfectants are degraded very easily by organic soil to ineffective products. Peracetic acid and hydrogen peroxide break down to the products that have been described earlier.

The breakdown products from the halogens vary with pH of the effluent, but in general, halide ions will be produced. The halogens should not be mixed with acid products, as chlorine will react with organic chemicals to produce organo-chloro compounds, which may be carcinogenic. The nonoxidizing disinfectants in modern products tend to consist of biodegradable compounds. The cationic products will adsorb on to organic material. The biguanides are incompatible with alkaline chemicals and will form a precipitate. (*See* **Effluents from Food Processing**: On-Site Processing of Waste; Disposal of Waste Water; Composition and Analysis.)

Analysis of Disinfectants in Waste Water

Obviously, detection will tend to depend on the concentration of disinfectant present. The oxidizing disinfectants are unlikely to be detected. Halide ions can be detected but cannot be identified as coming from the disinfectant.

Using an available chlorine probe, chlorine may be detected up to 200 p.p.m., but because of the presence of organic material and other chemicals, the presence of available chlorine may not be detected. As with chlorine, available iodine can be detected using a probe, but iodine is converted very quickly to iodide. The breakdown products of peracetic acid and hydrogen peroxide are unlikely to be detected.

For the quaternary ammonium compounds, the biguanides and the amphoterics, it would be necessary to know the specific active molecule to be able to quantify these activities in effluent. The active content could then be determined by HPLC.

Acid anionics can be detected in the effluent by determining the anionic content.

Comparison with Steam

There is no chemical suitable for use as a disinfectant in the food factory that can compete with steam. It is effective against bacteria, molds, yeasts, bacterial spores, and viruses. It is not affected by soil and hard water. There are no corrosion or stability problems, and it leaves no residues. The drawbacks are that it cannot be used with heat-sensitive plant materials, and it needs careful use to avoid human contact.

See also: **Effluents from Food Processing**: On-Site Processing of Waste; Disposal of Waste Water; Composition and Analysis; **Spoilage**: Bacterial Spoilage; Molds in Spoilage; Yeasts in Spoilage

Further Reading

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Overall Approach

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Background

Plant and equipment is generally cleaned for one of two reasons.

1. Microbiological
   - defined by required final product microbiological quality.
2. Process