Choice and use of chemical sanitizers in the food industry

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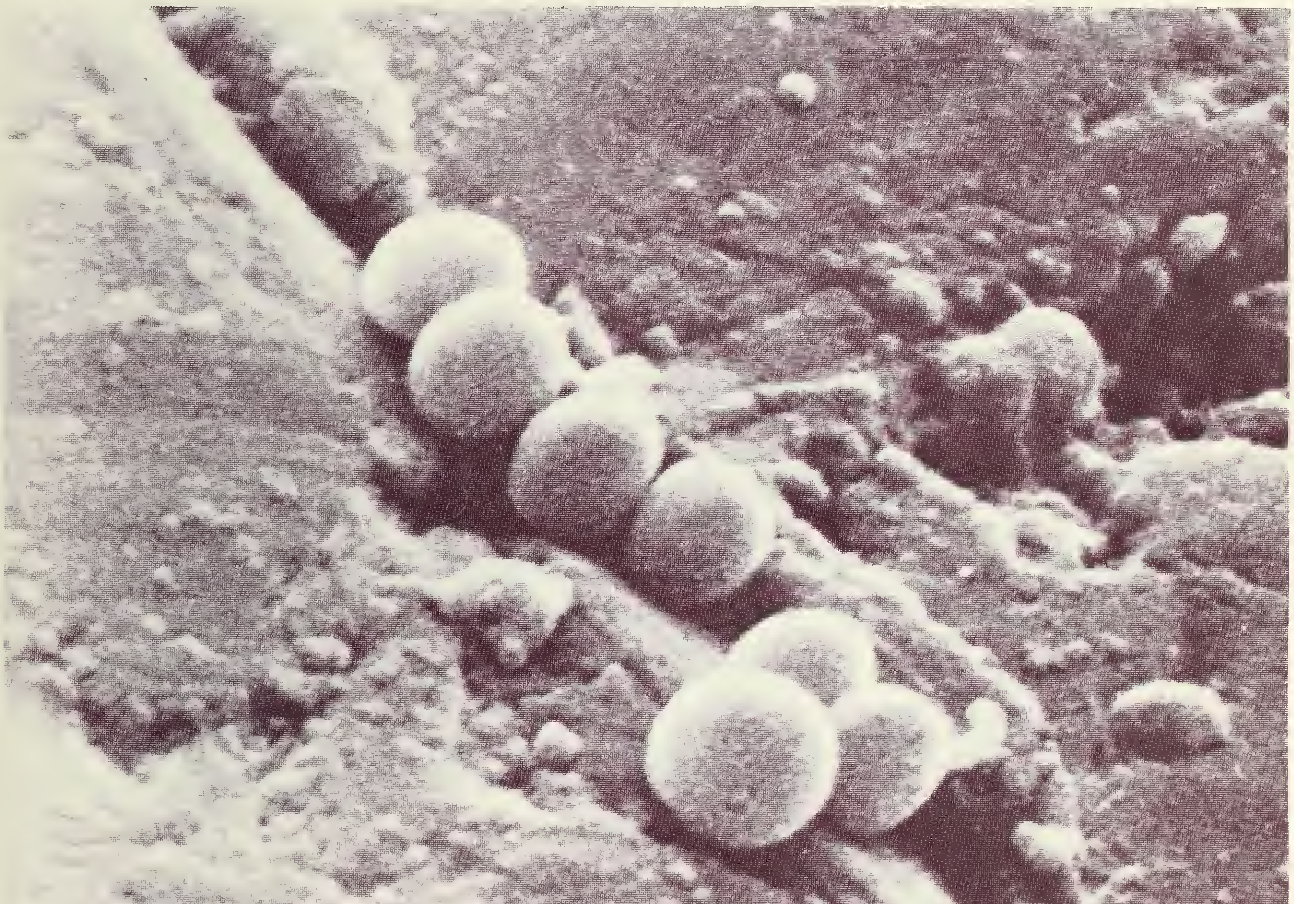

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Choice and use of chemical sanitizers in the food industry

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The Meat Hygiene Division, Food Production and Inspection Branch, Agriculture Canada, compiles a list of approved materials, agents, compounds, paints, and plant equipment that have been found acceptable for use in registered food plants in Canada. A charge is made for each copy of the list.

cover photograph
Bacterial cells (*Staphylococcus aureus* ATCC 6538) lodged in a scratch on the surface of stainless steel (viewed by scanning electron microscopy).

CONTENTS

FOREWORD

To be safe for human consumption, food products should be free from pathogenic bacteria and foreign materials. To meet marketing needs, products require longer shelf-life, better palatability, and excellent presentation. These are the reasons for preventing filth and bacteria from spoiling food.

Cleanliness and sanitation are of utmost importance in food plants. Personnel, equipment, and premises should meet high standards of cleanliness and hygiene.

The purpose of cleaning is to eliminate residues that may contaminate foods, either directly or indirectly by sustaining the growth of microorganisms that may later be transferred to food. Cleaning should be done on a daily basis, or more often if needed. Appropriate approved cleaning compounds should be used to remove all foreign matter. Regular inspection schedules should also be followed to assess cleanliness periodically.

The purpose of sanitizing is to destroy most, if not all, living microorganisms present on surfaces and in the processing environment. Sanitizing also should be done daily, but only after cleaning. It is important to realize that sanitizing can never be a substitute for cleaning. Surfaces should be inspected regularly for microorganisms, to assess the efficiency of sanitizing.

INTRODUCTION

Cleaning and cleaners

Suitable methods of cleaning and disinfection of equipment in food processing plants can vary, but basically they consist of six steps:

- removal of loosely attached debris using hot or cold water;
- application of a detergent to emulsify the remaining material;
- scrubbing or high-pressure cleaning of soiled surfaces;
- application of hot (77°C) water or a chemical disinfectant;
- waiting for sufficient exposure;
- rinsing off the disinfectant with potable water.

The choice of a water-based cleaner from the seven classes available is made on the basis of the nature of the material to be removed, the chemical stability of the surfaces to be cleaned, the quality of water available, and the allowable cost.

The major classes of cleaners in use include basic alkalis, acids, surfactants, complex phosphates, chelating compounds (such as water softeners), defoamers, and chlorine (at a pH greater than 12).

When carried out properly in processing plants, cleaning is a useful method of decontamination because at least 90% of the organisms present are removed with the unwanted food residues.

Disinfection and sanitizers

Treatment with heat (at 77°C for more than 30 sec and up to 5 min) or with a chemical disinfectant after cleaning is the most effective way of dealing with the living organisms not removed from equipment surfaces by vigorous cleaning. Chemicals that reduce disease-causing organisms to insignificant levels are commonly referred to as disinfectants. These same compounds are known as sanitizers when applied to equipment in food processing establishments.

Chemical sanitizers are one of the most powerful tools available for use in cleaning systems; however, their ability to kill residual organisms is substantially reduced if good housekeeping practices and efficient cleaning methods are not used to remove food debris prior to sanitizing. When properly and regularly cleaned (for example, at intervals of 2 to 4 hours during continuous operations), food contact surfaces harbor few organisms and the need for disinfection is also reduced. Under most conditions, use of sanitizers increases the shelf-life and quality of processed foods and, in addition, reduces the risk to public health from pathogens that might otherwise still be present on cleaned surfaces.

Just as it is important to use proper cleaning techniques in the plant, it is essential to apply sanitizers in accordance with instructions on their labels. Some sanitizers can be combined for better effect, but others when mixed become inactive. For example, when acid-anionic and quaternary ammonium sanitizers are used together they can neutralize each other, but if used one after the other they can be very effective.

In addition to compatibility, other characteristics that determine the suitability of sanitizers must be considered. These include response to pH and temperature, strength, persistence, toxicity, corrosiveness, and cost. This guide has been prepared to help food processors select the right type of product and conditions for its use, in order to obtain the maximum efficiency at the lowest possible cost.

GENERAL BEHAVIOR OF MICROORGANISMS

Types of microorganisms

Since neither cleaning nor sanitizing, nor the two processes together, can sterilize food contact surfaces and associated work areas or free them completely from microorganisms, there is no way sanitary control can be achieved without a regular program of cleaning and sanitation. Food processors have to deal with microorganisms on a recurrent or regular basis, because these organisms are continually introduced with the food being processed, can grow in the food, and may be transferred to other areas of the plant. It is therefore important to have some understanding of factors that influence their survival and potential for growth, with subsequent development of early food spoilage and human illness.

Bacteria

Bacteria are single-cell microorganisms, which reproduce simply by division into two identical cells. Two types, *Bacillus* and *Clostridium*, can also develop dormant forms called spores which are generally more heat resistant. Bacteria are classified into two main groups: Gram-positive (+), in which the cell wall has a low lipid or fat content, and Gram-negative (–), in which the cell wall has a high lipid content. These differences in mode of reproduction and composition of the cell wall are the reasons why the response of bacteria to chemical sanitizers is extremely variable.

Generally, Gram(+) bacteria are easier to destroy than Gram(–), which in turn are easier to destroy than spores of *Bacillus* and *Clostridium*. However, there is always a possibility that some bacteria may show unexpected resistance to specific sanitizers under certain conditions. In some situations *Staphylococci* and *Streptococci* are more resistant than the Gram(–) *Enterobacteriaceae*; nonetheless, it is clear that vegetative forms of bacteria are destroyed by cleaning and disinfection methods.

Under optimal growth conditions, including temperatures of 24–46°C (75–115°F), bacteria may double their number every 10–20 min. Therefore one single cell may divide into more than 35 000 within 2.5–5 hours. Hence, it is mandatory to keep the initial population as low as possible and to create such adverse conditions that growth is greatly reduced if not blocked.

Yeasts

Yeasts are single-cell microorganisms which reproduce asexually by budding or sexually by the pairing of two mother cells, which can also lead to spore formation. Since the yeast cell wall consists mainly of sugar polymers (low in lipid), it also is Gram(+). Yeasts that naturally contaminate human food are of concern more from the point of view of food spoilage than from the perspective of public health.

Being used widely in many food processes, yeasts are grown on a large scale. They are responsible for desirable fermentations which lead to the production of bread, beer, wine, and distilled spirits. Unfortunately, some strains of yeast cause a substantial amount of food spoilage and are responsible for significant reduction in the shelf-life of foods such as jams, syrups, processed meats, and cottage cheese. Yeasts can grow with or without oxygen and cause spoilage of even very acidic foods (such as yogurt).

Molds

Molds are more complex microorganisms which grow to the extent of being visible to the naked eye. They reproduce in many different ways; however, they usually produce a large number of *spores*. These spores are readily spread by draughts of air or by water splashed on contaminated surfaces.

Despite the fact that mold spores are less resistant than bacterial spores, they are still difficult to destroy. The occurrence of heavy contamination by mold spores is always a critical problem when it comes to chemical sanitizing.

Viruses

Viruses are not a problem in food processing plants under sanitary conditions, with the possible exception of bacteriophage in starter cultures used in the dairy industry.

Conditions for survival and growth

Water

All living organisms need water to survive; many bacteria die if simply dried. Therefore, drying surfaces helps greatly in keeping contamination extremely low.

It has been observed that spores and some pathogenic bacteria (*Staphylococcus aureus* and *Mycobacterium tuberculosis*) survive very well when dry; therefore, chemical sanitizers must be used before surfaces are dried.

Food

Growth cannot occur on a surface that contains no nutrients to feed bacteria. Thorough cleaning with appropriate chemicals should remove all debris, thus leaving no place for bacteria to thrive and grow. Chemical sanitizing should be considered as another safety measure to assist in reducing the number of contaminating microorganisms, and is not a substitute for cleaning.

Temperature

The optimal growth temperature for microorganisms may be as low as 5°C or as high as 60°C, depending upon the individual organisms.

Refrigerating contaminated foods or surfaces does not disinfect them and bacteria may easily survive at low temperatures, even below the freezing point. No one should rely on cold temperatures to reduce contamination. Most common microorganisms stop growing, or grow at a very slow rate, if temperature is lowered; but as soon as storage conditions permit, these organisms, if present in large numbers, grow and rapidly spoil the product.

pH

For each species there is an optimal pH range for growth. Generally speaking, acidic conditions inhibit growth of most bacteria. If the pH is below 2.5 or above 10 there is very little chance that microorganisms will survive. This is the reason why a thorough cleaning conducted at pH 10 or above followed by acidic treatment at pH 2.5 or less kills almost every type of bacteria.

Food-borne disease

Illness developing after the consumption of contaminated food can be either an infection or an intoxication.

Infections

Food infections are established by the entrance, survival, and growth of a pathogenic microorganism in the body. Infection from food-borne pathogens such as *Salmonella* occur in the living tissue of the intestinal wall. *Clostridum perfringens* causes an infection but the body also reacts to the production of toxins by the organism.

Intoxications

Food intoxications are caused by the ingestion of poisonous or toxic materials formed by pathogenic organisms during their growth in food. These toxic materials or toxins are of two types, either endotoxins or exotoxins. Endotoxins are present within the cell and are released on the death of the microorganism. Exotoxins are excreted by the living microorganism and remain toxic long after their death. Some of these toxins are heat stable (for example, those produced by *Staphylococcus aureus*), and can retain their potency in food even after boiling for 30 min. Thus, a contaminated food may no longer harbor live microorganisms but still be very dangerous.

It is evident that killing the offending microorganisms is not always sufficient; their toxins have to be destroyed also. It is much easier to avoid contamination by live microorganisms than to inactivate toxins once present in the foods. Sanitation should aim at maintaining low bacterial numbers rather than reducing high counts, and is thus a continuous responsibility in the food processing plant.

SANITIZERS

Classes

The three main classes of sanitizers used in food processing operations to reduce the numbers of living organisms to acceptable standards are heat, radiation, and chemical agents (Guthrie 1980).

Heat may be applied as flowing steam to yield 77° C (170° F) for 15 min or 93° C (200° F) for 5 min, with at least 1 min exposure to a steam jet. Hot water is an effective sanitizer if applied at 77° C for 2 min on dishes and utensils, but food processing equipment must be treated for 5 min at 77° C. Hot air is effective when used at 82° C (180° F) and applied for 20 min.

Radiation in the form of ultraviolet light destroys microorganisms on surfaces only in the direct rays of light. Contact time should exceed 2 min.

Chemical agents take a variety of forms and are the group in which we are most interested. These agents include chlorine-bearing compounds, quaternary ammonium compounds, aldoquaternary compounds, acid-anionic compounds, aldehydes, amphoterics, and iodine complexes. Although used in hospitals, compounds such as phenolics, formaldehyde, and salts of heavy metals are either too toxic or corrosive for use on food contact surfaces.

Mode of action

The manner in which the different sanitizers act is quite diverse and complicated in some instances, because sanitizers can act in more than one way. For example, oxidizers can cause chemical change or destruction but at the same time many bacteria may be poisoned through metabolic interference by liberated oxygen.

Chemical destruction or denaturation

Strong acids and bases are corrosive by virtue of their acidity or alkalinity, and rapidly destroy organic matter. Some of them may be used to kill microorganisms. Of course, the major limitation to the use of such products is that they corrode the equipment and materials used in food plants. Hazards in handling them are also a significant limiting factor. Besides pH, a variety of other types of chemical reactions may be used to sanitize.

Oxidizers are commonly used to destroy bacteria quickly; hypochlorites, complex chlorinated organic compounds, hydrogen peroxide, and peracetic acid are among the most widely used representatives of this class. Disinfection of carton materials by passage through a concentrated solution of hydrogen peroxide has permitted the development of aseptic package filling in the food industry. Halogen-releasing compounds such as iodophors and bromine complexes which yield toxic iodine and bromine act in a similar way and are also widely used.

Typically, chemical destruction is a quick phenomenon, acting indiscriminately on all organic matter, and also on metals, but at variable rates. Since phospholipids are highly resistant to chemical attack, one may expect Gram(–) bacteria, which contain relatively large quantities of phospholipid in their cell walls, to be more resistant than others to this kind of sanitizing action.

Metabolic interference

Destruction by metabolic interference might be described as a poisoning of the living cells. Generally, the primary action of chemicals is directed at the cell wall and associated membrane. Weakening or destruction of these may be followed by secondary action within the cell, which loses the ability to generate vital energy from nutrients. This leads to cellular death. The exact nature of lethal events are still poorly understood, but are under study.

The important things to remember are the property of organic matter to interfere with or block the activity of the sanitizer, and the ability of some strains of microorganisms to acquire resistance to a particular antimetabolic chemical sanitizer through mutation. Therefore, it is important when using this type of chemical to follow proper procedures and ensure the elimination of as many viable organisms as possible. It is also wise to alternate sanitizers at regular intervals, determined either experimentally or by experience.

Inhibition of reproduction

Some sanitizers, while not lethally destructive to a living cell, may interfere with its ability to reproduce by blocking the duplication of material in the nucleus of the cell. Often the chemical causes a protein chain to be assembled incorrectly. Others may interfere at specific sites, such as the sulfhydryl groups of amino acids, to prevent action of enzymes vital to reproduction.

Use of products that act in this manner does not eliminate all viable or living organisms. They halt reproductive growth, and when the sanitizer is rinsed from surfaces or becomes depleted, the viable bacteria may be poised, ready to grow after repair of their injuries.

In some instances a large increase in chemical concentration may produce an immediate lethal effect on some bacteria; however, to avoid any undesirable selection of resistant organisms, contact time should be the maximum allowed by manufacturers' instruction.

EVALUATION OF CHEMICAL SANITIZERS

Basic criteria

Choice of a chemical sanitizer should be based on:

- bactericidal potency (good killing power at low concentration);
- bactericidal spectrum (wide or selective depending upon intended uses);
- tolerance for adverse environmental conditions (organic residues, water hardness, detergent residues, pH, etc.);
- good surface-active properties (wetting ability);
- stability (concentrated and diluted);
- reasonable price;
- low level of taste and odor;
- low toxicity and irritant potential for the user;
- lack of interference with the manufacturing process.

Factors affecting sanitizer efficacy

Time, temperature, and concentration relationships

The effectiveness of sanitizing action is closely related to the temperature at which the procedure is carried out; the optimum temperature is in the range of 21–38°C (70–100°F). Some sanitizers like iodine are volatile and dissipate rapidly at temperatures above 50°C (120°F) whereas others are completely ineffective at temperatures of 4.5°C (40°F) or lower.

Unfortunately, in most instances the relationship between temperature and rate of kill is not known. Generally speaking, products that act by metabolic or reproductive interference become significantly more effective when the temperature is raised from 4°C to 50°C. Those acting principally by chemical destruction show much less change in efficacy when the temperature is raised. It should also be remembered that corrosion at elevated temperatures may quickly become a significant problem. Data to illustrate the relationships among time, temperature, and concentration, obtained during a recent study, are shown in Table 1.

The extent to which temperature causes stress to microorganisms or inhibits their growth, and the degree of its effect when combined with a sanitizer, depend on the nature of the target microorganisms. A few organisms grow optimally at temperatures under 20°C whereas others grow best at 55°C.

Temperature can be easily monitored in CIP (clean-in-place) systems and should be used to advantage whenever possible. On the other hand, exterior sanitizing of machinery does not allow for much temperature increase, since a hot sanitizer solution cools down very quickly when put in contact with cold machines. It is therefore recommended that the contact time be extended as much as possible. It is best to sanitize the equipment immediately after cleaning, and rinse a few minutes before the equipment is used.

Table 1 Minimum effective concentrations of various sanitizers against *Pseudomonas aeruginosa* as measured by the use-dilution test (AOAC 1980); temperature and contact time are the variables of the system; concentrations are expressed as ppm of active ingredients[1]

Sanitizer[2]	Contact time (min)	Concentration at temperatures of: 4° C (ppm)	20° C (ppm)	37° C (ppm)	50° C (ppm)
acid-anionic	10	375	225	50	20
(Per-vad)	20	375	225	50	20
	30	175	150	40	20
chlorhexidine acetate	10	12 500	5 500	250	150
(Hibitane)	20	7 500	2 000	250	50
	30	7 500	2 000	225	60
quaternary ammonium	10	4 250	2 250	1 000	275
(FP 787)	20	2 000	425	425	275
	30	1 500	425	325	275
glutaraldehyde	10	65 000	8 500	750	750
	20	32 500	2 000	750	550
	30	32 500	2 000	750	425
aldoquaternary compound	10	2 750	1 100	225	110
(Quatal)	20	1 000	650	225	110
	30	1 000	550	85	50
sodium hypochlorite	10	375	175	100	*
	20	110	65	45	*
	30	50	50	25	*
iodophor	10	110	40	40	*
(Mikroklene)	20	40	40	40	*
	30	40	40	20	*
amphoteric	10	12 500	12 500	2 250	850
(Tego 51)	20	11 000	7 500	275	125
	30	3 250	3 250	275	100

[1]Gélinas et al. (1981).

[2] Mention of a brand name does not constitute endorsement or mean these are the best or only compounds of this particular type available for use.

*Unstable at this temperature.

Organic residues

Most sanitizers are adversely affected by the presence of organic matter. Unfortunately, when proper cleaning is often overlooked in the hope that sanitizing will resolve contamination problems, the sanitizer is actually rendered next to useless.

The type of sanitizer and the nature of the food debris control the extent of loss in effectiveness. Commonly used sanitizers like hypochlorites and iodophors do not tolerate organic residues. Quaternary ammonium compounds, acid-anionics, aldoquaternary compounds, and amphoterics are slightly more tolerant, and aldehyde seems to be largely unaffected.

Laboratory testing has shown that cleaner-sanitizers offer little safety unless their solutions are changed often to avoid heavy accumulation of debris. Hand dips should be checked carefully to make sure that they do not become a source of contamination themselves.

Water hardness

Although the antibacterial effectiveness of hypochlorite is not substantially affected by extreme water hardness (500 ppm calcium plus magnesium), quaternary ammonium compounds should not be used where the water is hard (more than 200 ppm). Many quaternary ammonium compounds incorporate chelating agents that permit effectiveness even in hard water. Extremely hard water may also reduce the efficacy of iodophors when used at low levels.

Type of surface

The type of surface to be sanitized is a factor of considerable importance which is almost totally neglected in tests of a sanitizer's effectiveness. A recent study (Gelinas et al. 1981), involving stainless steel, polypropylene, and an aluminum alloy, revealed considerable variance in the efficient use-dilution concentration of some sanitizers when used on different substances. Therefore, a careful laboratory evaluation of sanitizers should include all major surfaces found in the plant where the products will be used.

Acidic materials like iodophors and acid-anionic complexes obviously should not be used on alkaline substrates like concrete. Standard-grade aluminum is severely affected by acid-anionics and hypochlorites.

It is important to note that organic chlorine compounds, hypochlorites, iodophors, quaternary ammonium compounds, and amphoterics are all suitable for use on food contact surfaces made of stainless steel, glass and ceramic ware, plastic, wood, and rubber, and even on some painted surfaces (Lewis 1980).

A summary of how the major types of sanitizers are affected by environmental conditions, and also some important individual characteristics of sanitizers, are presented in Table 2.

Length of exposure

Under optimum conditions of sanitization the time of exposure should be at least 2 min. Contact with the sanitizer is usually recommended to be in excess of 10 min, since conditions for application are usually not optimal for sanitizer action (Table 1).

Table 2 Proposed classification of tested disinfectants[1]

Disinfectant group	Mode of action	General reactivity	Heat and light stability	Tolerance for organic matter	Temperature dependence	Low-temperature efficacy
1. Sodium hypochlorite	General cell oxidation	High	Low	Low	Low	High
Iodophor		↑	↓	↓	↓	↑
2. Aldoquaternary complex	General cell permeability denaturation	↑	↓	↓	↓	↑
Quaternary ammonium compound		↑	↓	↓	↓	↑
Anionic acid		↑	↓	↓	↓	↑
3. Chlorhexidine acetate	not fully understood	↑	↓	↓	↓	↑
Amphoteric surfactant		↑	↓	↓	↓	↑
4. Glutaraldehyde	Fixation of external cell layers	Low	High	High	High	Low

[1] In brief from Hugo (1965).

Testing sanitizer efficacy

Laboratory testing

Many methods have been proposed to evaluate the efficacy of sanitizers by establishing the most effective dilution of the compound under in-use or "use-dilution" conditions. There are three main methods: suspension methods, tests with inert carriers, and agar tests.

Suspension methods are those where a known concentration of a test microorganism in liquid is exposed to a specific concentration of sanitizer. Survivors are counted and the rate of kill is established.

In tests with inert carriers, the carriers (such as metal rings) are contaminated with microorganisms, drained, and exposed to the sanitizer. The carriers are removed and transferred to a liquid that allows any living organisms to grow.

Agar tests can be used to test antibiotic-like substances. Sanitizer-impregnated disks are dropped on a layer of nutrient gel (agar) that contains bacteria. Effectiveness of the sanitizer is evaluated by the extent to which bacteria are inhibited around the disk.

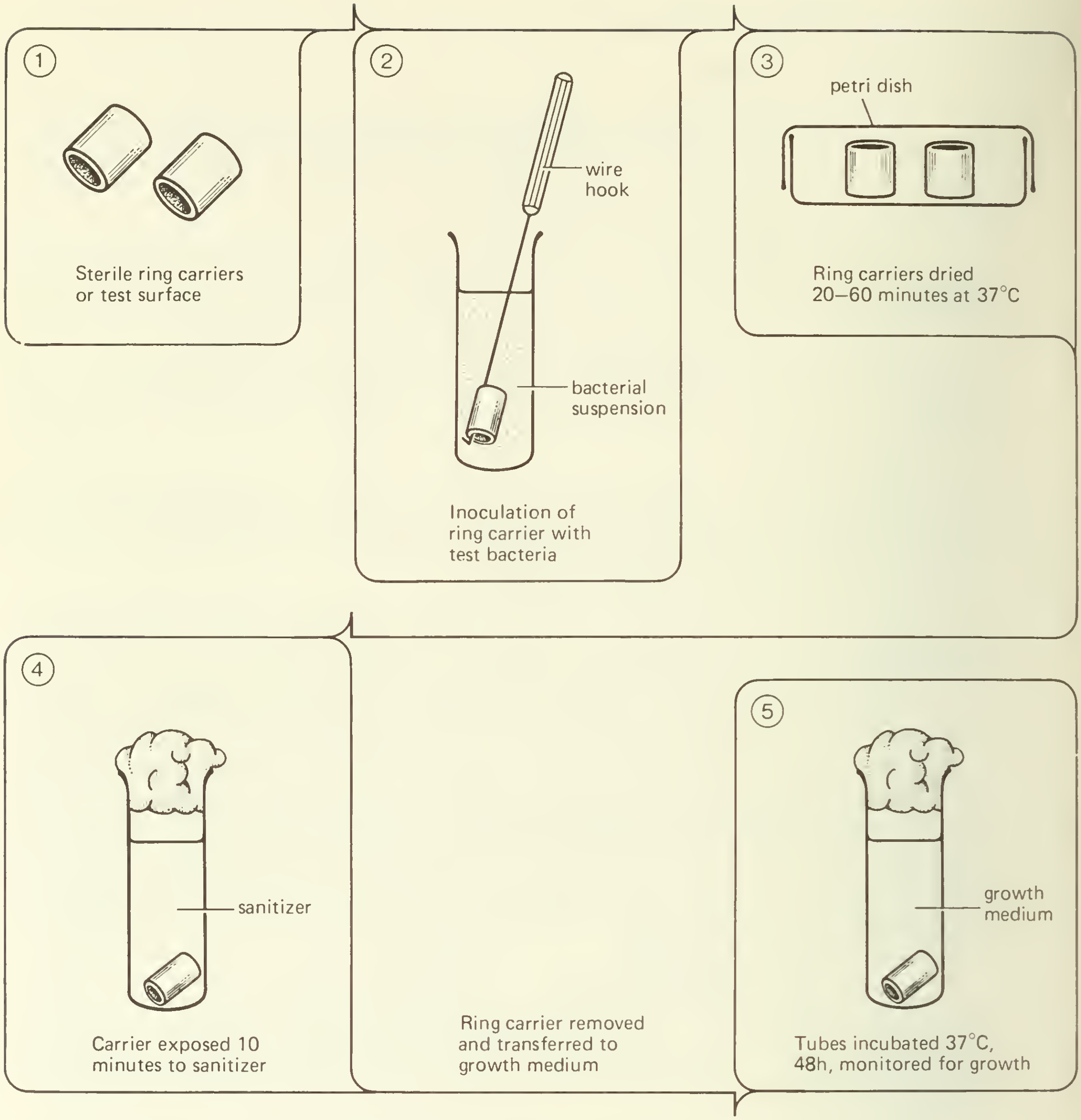
The "phenol coefficient" method, widely used a few years ago, is now considered by some people to be unreliable, particularly when applied to sanitizers that will be used for surface decontamination.

For the purpose of a sound evaluation, we consider that the AOAC "use-dilution" test (an inert-carrier type of test) and some of its variations reveal the conditions under which a given sanitizer will totally destroy living microorganisms present on a specific surface. Concentrations found effective may be much higher than what is generally required for practical sanitizing purposes, but these tests do allow some realistic comparisons to be made among various products. Also, essential factors such as the type of surface, interference by organic residues, and temperature may be studied and guidelines for use set accordingly.

AOAC "use-dilution" method. Essential steps of the method are explained in Figure 1. To be statistically significant, the test should be repeated 60 times. For practical purposes, 10 repetitions should suffice. The method is described in detail in the 13th edition of the AOAC manual (AOAC 1980).

Modifications of test procedures. To relate the standard tests more closely to conditions under which the sanitizers will be used in the plant, the following modifications to the test procedures are recommended.

- Water hardness: To determine the influence of water hardness on sanitizer efficacy, the germicidal and detergents sanitizers method (AOAC 1980) is used. In the standard method, distilled water is replaced with sterile water of known hardness. To assess the sanitizer's efficacy with the water actually found in the plant, it is suggested that an appropriate amount of water be sterilized and used for testing. It would be helpful to run analyses of pH, hardness, and iron before and after sterilizing in order to define the exact water conditions.
- Organic residues: The Whitmore and Miner (1976) method may be adopted. We would suggest that you use organic residues typical of your



The highest dilution which kills test organisms on ten carriers in a 10 minute interval represents presumed safe "use-dilution" for practical disinfection.

Figure 1. AOAC "use-dilution" method for testing sanitizer effectiveness.

industry (e.g., milk powder, dried blood) to assess the effect on sanitizer efficacy.

- Type of surface: Since the type of surface has a great bearing on the activity of sanitizers, we recommend that suitable samples of food contact surfaces from the plant actually be used for testing. Cleaning agents used in the experiments should be the same as those currently used in the plant to clean the surfaces. In this way, the test would take into account the cleaning method as well as the efficacy of the sanitizer.

In-plant testing

Unless a standard procedure is adopted, the in-plant part of the evaluation program may be misleading and without any correlation with laboratory results.

There are two main types of sampling methods to evaluate surface contamination: use of swabs of various types, and direct contact of the surface with solidified agar (e.g., Rodac plates).

The first method has the advantages of allowing recessed areas to be reached and also making use of some abrasive effect to dislodge microorganisms from the surface. It is, however, sometimes difficult to determine exactly the surface area sampled if it is not flat.

In some instances, when bacteria that may be present are of the anaerobic type in thin films (leuconostocs, lactobacilli), one may use swabs wetted with a sterile solution containing an abrasive material, (e.g., calcined silica), to efficiently remove all living microorganisms.

Rodac plates are easier to use and interpret. However, they can be used on flat surfaces only and they do not allow for easy further identification of bacteria. We would not recommend their use in an evaluation program; they should be restricted to routine control.

A typical procedure for testing the surface efficacy of a sanitizer would be:

- swabbing of suspected areas at the end of production;
- swabbing some areas immediately after regular cleaning;
- applying tested sanitizer at recommended concentration;
- swabbing after minimal recommended contact time;
- swabbing surfaces when ready for production.

In a preliminary evaluation, we would suggest that the swabs be examined with four different media to obtain the following counts:

- total count (SPC agar);
- yeasts and molds (PDA agar);
- coliforms (Brilliant green broth);
- staphylococci (Baird-Parker agar).

If the presence of anaerobes is suspected, appropriate agars and techniques should be used (Holdeman et al. 1977).

General recommendations

We would like to stress again the fact that sanitary surfaces are essential in a food plant; however, it should be remembered that most contamination usually occurs during processing. It is futile to spend great time and effort on surface decontamination if good manufacturing practices are not followed.

On the basis of experience and our survey of published information, we make the following recommendations:

1. Do not rely too heavily upon unsubstantiated claims about a sanitizer. Request specific information, and if not available conduct your own tests.
2. Determine the practical "in-use" concentration of a product. Laboratory testing procedures should involve several test microorganisms including *Pseudomonas aeruginosa* and microbial contaminants from your plant. It may be necessary to hire the services of a laboratory to complete these tests.
3. Organic debris may adversely affect the efficacy of sanitizers. Check this possibility using residues from your plant. CLEAN FIRST.
4. Do not use construction materials that are difficult to sanitize; machines should be easy to clean and sanitize. Use an inert-carrier testing technique (AOAC 1980).
5. Use only corrosion-resistant materials; the range of available sanitizers will be wider.
6. Regularly check the concentration of unstable sanitizers (for example, iodophors, hypochlorites).
7. Carefully examine the possible interference of sanitizers with your manufacturing process. Avoid food contamination.
8. Establish the most economical time, temperature, and concentration ratio for each sanitizing product.
9. Correlate laboratory tests with practical in-plant evaluation.

GENERAL SELECTION PROCEDURES FOR SANITIZERS

1. IDENTIFY and select target microorganisms; prepare several strains, including *Pseudomonas aeruginosa*; work also with strains isolated from the factory.
2. DEFINE constraints to be observed:
   - in the factory: working time available; surface types; quality of cleaning.
   - related to products: corrosive strength; stability; toxicity; rinsing quality of bactericidal solutions.
3. STUDY behavior of products in the laboratory (*in vitro*), using approved test procedures.
4. CONFIRM results found in the laboratory by using factory (*in situ*) tests.
5. CALCULATE the most economical concentration for effective sanitation (see next section).

A collection of information in Table 3 very briefly summarizes how selection of a sanitizer can begin by consideration of the above factors.

Table 3 General recommendations* for the use of chemical sanitizers in a food processing plant

Intended use	Recommended sanitizer
Gram(–) psychrotrophs (*Pseudomonas*)	acid-anionic, chlorhexidine acetate, glutaraldehyde, sodium hypochlorite, iodophor
Gram(+) vegetative cells	quaternary ammonium, aldoquaternary, iodophors, chlorine
bacterial spores	chlorine (or others)
coliforms	sodium hypochlorite, iodophor (or others)
hard water	acid-anionic, sodium hypochlorite, glutaraldehyde, aldoquaternary
aluminum equipment	glutaraldehyde, amphoteric, aldoquaternary
equipment just before use	iodophor, chlorine (or others)
equipment to be stored	quaternary ammonium, glutaraldehyde, aldoquaternary (or others)

*From Guthrie (1980) and Gélinas et al. (1981).

Notes: Physical constraints such as corrosion, type of surface, interference with manufacturing processes etc., have to be taken into consideration.

Recommendation of a particular type of sanitizer does not necessarily imply that other types would not be suitable for a given purpose.

QUALITY/PRICE RELATIONSHIP

Although the relationship between quality and price is complex, in general its analysis requires the use of both *in vitro* and *in situ* results. An example of this kind of calculation is given below. It is based on the following equation:

Cost = cost of sanitizer needed + cost of heating water to desired temperature

It is assumed that three products, A, B, and C, are available. We know their effectiveness thresholds (that is, the lowest concentration at which they kill all bacteria at a given temperature of the solution).

Sanitizer	Sanitizer cost ($/L)	Effectiveness threshold—percentage concentration at temperatures of: 4° C (%)	20° C (%)	40° C (%)	70° C (%)
A	1.80	2.0	1.5	1.0	1.00
B	3.25	0.5	0.2	0.1	0.05
C	1.05	1.0	0.8	0.6	unacceptable

In this example, we assume that 1000 L of bactericide solution (cleaning through circulation) are to be used. The cost of sanitizer needed is thus the sanitizer cost per litre multiplied by its percentage concentration in the solution, and by the quantity of solution to be used.

To find the cost of heating water to the desired temperature, let us assume that the water available has a temperature of 10° C. To heat it further requires the consumption of oil, which costs $0.40/L. The heating cost is calculated by multiplying the 1000 L of solution by the number of degrees by which the temperature is to be raised, and by the price of oil per litre divided by 10 000 (representing the energy in Calories generated by one litre of fuel).

The most economical application of the products tested is thus calculated as follows:

Product A

$$4°C: (1.80 \times 2.0\% \times 1000) + (0) = \$36.00$$
$$20°C: (1.80 \times 1.5\% \times 1000) + \left(1000\,[20-10] \times \frac{0.40}{10\,000}\right) = \$27.40$$
$$40°C: (1.80 \times 1.0\% \times 1000) + \left(1000\,[40-10] \times \frac{0.40}{10\,000}\right) = \$19.20$$
$$70°C: (1.80 \times 1.0\% \times 1000) + \left(1000\,[70-10] \times \frac{0.40}{10\,000}\right) = \$20.40$$

Thus, the most economic and effective application of sanitizer A would be a 1% solution applied at a temperature of 40° C.

Product B

$$4°C: (3.25 \times 0.5\% \times 1000) + (0) = \$16.25$$
$$20°C: (3.25 \times 0.2\% \times 1000) + \left(1000\,[20-10] \times \frac{0.4}{10\,000}\right) = \$\ 6.90$$
$$40°C: (3.25 \times 0.1\% \times 1000) + \left(1000\,[40-10] \times \frac{0.4}{10\,000}\right) = \$\ 4.45$$
$$70°C: (3.25 \times 0.05\% \times 1000) + \left(1000\,[70-10] \times \frac{0.4}{10\,000}\right) = \$\ 4.03$$

Sanitizer B is most economically and effectively used when applied at a concentration of 0.05% and a temperature of 70° C.

Product C

$$4°C: (1.05 \times 1.0\% \times 1000) + (0) = \$10.50$$
$$20°C: (1.05 \times 0.8\% \times 1000) + \left(1000\,[20-10] \times \frac{0.4}{10\,000}\right) = \$\ 8.80$$
$$40°C: (1.05 \times 0.6\% \times 1000) + \left(1000\,[40-10] \times \frac{0.4}{10\,000}\right) = \$\ 7.50$$

70° C: unacceptable

When sanitizer C is used at a concentration of 0.6% at 40° C, the best results for the least cost will be attained.

It should be clear that applying the highest concentration of sanitizer is not always the best and most sensible way to use these compounds. Considerable savings and improvement in sanitizing efficacy can be realized if the above calculations are carried out.

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