General disinfection guidelines

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Summary: Cleaning and disinfection of surfaces which have been in contact with animals, poultry or organic material is a vital element in controlling bacterial and viral diseases, and ensuring the wholesomeness and safety of foods. The thoroughness of pre-disinfection cleaning is the most important determinant of the efficacy of disinfection processes.

Disinfectant users and officials responsible for the use of disinfectants must have clear goals and a sound plan of action. They must choose appropriate products, properly clean and prepare the site, and take the necessary steps to ensure the safety of animals, humans, equipment and the environment. They must also objectively evaluate the results of disinfection procedures.

Safe and effective disinfectant strategies require an understanding of the actions and toxicological hazards of the chosen products, a clear plan of action, regulatory discipline, conscientious documentation, responsible supervision and post-disinfection testing. Disinfection procedures and policies must meet legal and environmental requirements and the changing expectations of society.


INTRODUCTION

DISINFECTANTS, ANTISEPTICS, SANITIZERS AND STERILIZING AGENTS

Disinfection is the process of eliminating infectious organisms by using chemical or physical agents (1). The antimicrobial agents designated as disinfectants are sometimes used alternatively as sterilizing agents, sanitizers or antiseptics. For the most part, disinfectants used in animal health are relatively strong, usually toxic antimicrobial or biocidal chemicals, and are applied to contaminated surfaces. Those used in food processing are usually less toxic and more diluted. Modern disinfectants are complex formulations of chemicals, soaps, detergents, and compounds which improve penetration of the active ingredients. In fish farming, disinfectants are used to decontaminate ponds, tanks and equipment.

By most definitions, wound treatments, surgical scrubs, bovine teat dips and other preparations used on living tissues are called antiseptics or sanitizers. The subtle differences between disinfectants, sanitizers, antiseptics and sterilizing agents relate to the desired objectives, the composition and concentration of chemicals used, the time

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allowed for contact with treated surfaces, acceptable levels of residues, and the environments in which procedures are conducted.

Sterilizing agents are used to produce total destruction of microorganisms under controlled industrial, laboratory or hospital conditions. Heat, chemicals and irradiation are the most commonly-used sterilizing agents.

Sanitizers combine cleaning and disinfection functions on surfaces which are relatively free of gross contamination. They are used to reduce bacteria to safe levels on food- or water-handling equipment without causing adulteration of the product. Both sanitizers and disinfectants are used extensively in animal health disinfection.

Antiseptics inhibit the growth of microorganisms on living tissue. They are used in wound treatment and in preparing the skin for surgery. Antiseptics are usually the weakest and least toxic of the surface antimicrobials.

The articles contained in this double issue of the Scientific and Technical Review of the Office International des Epizooties (OIE) detail the use of sterilizing agents, sanitizers and antiseptics in the context of cleaning, sanitation, hygiene and disinfection functions associated with animal health, food production and food processing.

**DISINFECTION IN PERSPECTIVE**

Disinfectants and sanitizing agents are used throughout the food-production/food-processing chain.

On the production side, these products help to prevent the spread of animal disease.

On the processing side, disinfectants and sanitizers serve to minimize levels of microbes present in edible products, to control spoilage, and to reduce the likelihood of disease transmission by food or garbage. However, the use of disinfection, pasteurization, irradiation or thorough cooking cannot always achieve these goals. Current interest in reducing residues and microbial content in mass-produced, pre-packaged and rapidly-served foods has produced the hazard analysis and critical control point (HACCP) strategy. This strategy identifies crucial points where contaminants enter the food chain and where intervention will be productive. The HACCP strategy is used by regulatory agencies and commercial processors of animal, poultry and fish products.

Effective disinfection requires thorough cleaning prior to the application of chemicals. This is so important that the words cleaning and disinfection may be merged into a compound term with a singular meaning (sometimes presented as 'C & D').

The complexity of cleaning and disinfection in day-to-day-animal health and food processing activities is frequently underestimated, and the many variables complicating this process are easily overlooked.

The art and science of disinfection predates the development of the germ theory. Initially, it was observed that applying certain compounds reduced the odour of sewage and decaying carcasses. Disinfectant usage has developed from these empirical beginnings to a science of considerable magnitude. In animal health applications, disinfection technology still lacks the quantitative basis achieved in medical uses and food processing. Today, some experts debate the merits of many products, procedures and evaluation methodologies. However, with advances in chemistry, biochemistry, microbiology and molecular biology, the mechanisms of disinfectant actions are being elucidated (8) and a scientifically-based disinfection technology is emerging (6, 28).
Disinfection science is evolving. New products are emerging, such as foams, mists and complex synthetic compounds. The technological, political and environmental dimensions of disinfection science are expanding to complicate and revolutionize disinfection and sanitizing practices.

As applied in regulatory and on-the-farm animal disease control programmes, disinfection is one way of limiting transmission of infectious diseases. However, disinfectants alone will not eliminate infections if carrier animals are continually added to susceptible populations. Disease control professionals must consider all links in the complex epidemiological chains forged by infectious agents, as the latter move from reservoirs (where they survive and multiply) to new susceptible hosts. Most infectious diseases are spread by contact between susceptible populations and acutely-ill or chronically-infected carrier animals. The spread of other diseases requires host- and agent-specific insect vectors. Disinfection is most applicable to non-vector borne diseases acquired by contact with bodily discharges or other materials in yards, stalls, floors and vehicles, or on equipment. Most of the latter diseases are caused by bacteria which can multiply and survive outside living animals, and include enteric and respiratory bacterial infections, clostridial infections, or diseases such as brucellosis and tuberculosis.

Viral diseases are principally controlled by limiting contact between animals or by vaccination. However, disinfection can play a major role in the control of viral infections, as most viruses are inactivated by modern disinfectants (10). Surface disinfection is important in controlling viruses which survive in the environment after the removal of infected animals.

Disinfection science is continually challenged by new classes of infectious agents.

One group, the immunodeficiency viruses, includes the virus of acquired immunodeficiency syndrome (AIDS) in humans, which has counterparts in most animal species. The immunodeficiency viruses provide avenues for microorganisms once considered saprophytic opportunists to become invasive.

Another group, the prions, defy identification. They fail to stimulate immunological responses, persist for years in afflicted animals, and are resistant to heat and disinfectants. International concern about certain prion-caused diseases (scrapie and bovine spongiform encephalopathy) has led to the development of stringent international sanitary measures.

Advances in microbiological and disinfection technology have combined with public interest in worker safety, food safety and environmental preservation to produce major paradigm shifts in disinfection procedures. As the ramifications of these advances become more complex, it is essential to train disinfection workers in safe application and storage procedures.

DISINFECTION: RESPONSIBILITIES AND REQUIRED KNOWLEDGE

Individuals responsible for the application, certification or planning of activities and regulations related to cleaning and disinfection must periodically evaluate the scientific, technical and pragmatic logic of programmes. Requirements must be compatible with current technology and contemporary societal expectations. Effective disinfection requires knowledge, a clear plan of action, regulatory discipline, documentation and evaluation.
Disinfectant users and their supervisors must have clear goals for each procedure in each specific setting. They must understand the effective spectrum of the disinfectant being used, its limitations, and the potential hazards to users, bystanders, animals, equipment and the environment arising from use of the product. Hazards to people can arise from disinfectant toxicity or zoonotic infections acquired from the environment which is being disinfected. Economic factors must be secondary to safety considerations.

Knowledge of disinfection can be acquired from training courses, careful reading of labels, reference to checklists and study of the available literature. Written material on food-processing sanitation is abundant, but information on animal health disinfection is scant and scattered. There is a comprehensive book (1) on disinfection, sterilization and preservation, which contains detailed descriptions of disinfectant compounds, antimicrobial testing methods and disinfectant applications. In addition, several comprehensive treatises on veterinary and farm animal disinfection have been published (20, 13, 24, 25), and brief discussions of disinfection are found in several texts on veterinary medicine (26, 27, 31) and microbiology (9, 22, 30).

**BASIC PRINCIPLES OF DISINFECTION**

**Plans of action for disinfection**

In addition to the necessary knowledge, successful disinfection procedures, guidelines or regulations require a clear, succinct plan of action for each specific disinfectant application. The plan should describe the objectives of the application and the specific microorganisms to be eliminated. It should describe the pre-disinfection cleaning process, safety measures, dilution and application instructions, and the post-disinfection procedures by which the efficacy of the process will be measured. The plan of action should also detail the documentation required to provide regulatory certification.

**Regulatory surveillance and disinfection policies**

Regulatory surveillance may be required to ensure the following:

- maximum efficiency in product utilization
- application of all possible safety precautions for people, animals, equipment and the environment
- effective, carefully-engineered pre-disinfection cleaning
- conscientious application of disinfectants to the appropriate surfaces.

At the policy level, disinfectant procedures and regulations must be constantly reviewed and evaluated in the light of rapidly advancing technology and changing public values with respect to human safety, residue hazards and environmental awareness.

**Animal health applications and strategies**

In animal and poultry disease applications, targeted disinfectant measures focusing on specific organisms are performed at research facilities or during post-depopulation disinfection. Such focused disinfection permits selection of a disinfectant with a narrow but specific spectrum of antimicrobial activity.
Routine disinfection, sometimes called general disinfection, requires a broad spectrum of antimicrobial activity to combat a wide array of unspecified organisms. General disinfection is performed on farms, as well as at sales barns, stockyards, exhibition grounds, quarantine stations, zoological parks, abattoirs, poultry and fish hatcheries, and food-processing plants.

Selection of disinfection strategies is based on the disease control scenario and the suspected microorganism(s). Selection of disinfectants presents a challenge, as much of the literature on veterinary disinfectants follows a chemical-by-chemical approach. By contrast, the information in this double issue of the OIE Review is arranged in terms of location and disease control scenario. The chemical-by-chemical approach is used only to provide background information (16).

Many countries focus disease exclusion programmes on specific OIE Lists A or B diseases, and choose required disinfectants accordingly. Animal health officials frequently select and approve disinfectants for prescribed cleaning and disinfection activities, and promulgate regulations requiring the use of these products for specific regulatory procedures.

Under field conditions, one can only speculate about the potential for disease transmission due to contaminated surfaces. This potential depends on the concentration of contaminating organisms, and the specific environmental conditions influencing the multiplication and natural decay of the organisms.

Bacteria and fungi can survive and multiply on moist surfaces, particularly if organic material is present. Most bacteria are fragile (18), while some (e.g. Mycobacterium tuberculosis and members of the spore-forming genus Clostridium) are innately resistant under natural conditions. Natural and acquired resistance to disinfectants have been observed among bacteria (3).

Viruses usually replicate only in living cells. However, some viruses are highly resistant to normal environmental conditions and can survive outside living cells or tissues (9). Some viruses (e.g. the picornaviruses which cause foot and mouth disease [FMD] and swine vesicular disease) can survive for many months under certain conditions. Some poxviruses (e.g. the causal agents of sheep pox and contagious ecthyma) can survive for years under ideal natural conditions, as they are encased in protective protein coatings within scabs when they fall to the ground.

FACTORS AFFECTING THE EFFICACY OF DISINFECTANTS

Pre-application cleaning is the most important element of cleaning and disinfection. The efficacy of any selected disinfectant also depends on the target organisms, their requirements for multiplication, and their resistance to environmental conditions and chemicals. The concentration of disinfectant and the duration of contact with surfaces, the ambient temperature and many other factors are also involved (19).

However, extraneous organic material is the paramount factor in the outcome of any disinfection operation, as this material dilutes and rapidly neutralizes biocidal chemicals. Vigorous scrubbing and voluminous water flushing must therefore precede application of disinfectants. Neither large quantities of disinfectants nor high-pressure application can replace prudent and thorough pre-disinfection cleaning.
ESTIMATING THE EFFICACY OF DISINFECTANTS

The efficacy of disinfection is truly evidenced only by healthy animals and wholesome foods. There are many ways of estimating the antimicrobial spectrum of disinfectants (7), but few internationally-accepted standards exist for testing and evaluating the disinfectants used in animal health programmes. Some nations and trading blocs develop lists of approved disinfectants for specific regulatory situations. In some countries, regulatory agencies specify required tests for approval of disinfectants used in specific applications. Other countries accept approved lists which have been developed elsewhere, or arbitrarily determine disinfectant requirements. Still other countries have minimal requirements.

Most modern disinfectants are complex mixtures of chemical substances. The biocidal activity of such mixtures cannot be measured by simple chemical analysis and must be determined by complex bioassay procedures.

Various approaches are used to test disinfectant activity against viruses, spores and vegetative forms of bacteria (6, 7, 22, 30, 21). Most work on biocidal efficacy has been performed using bacteria. These testing procedures are subject to multiple variables which produce discrepant results, contradictory interpretations and controversies. This presents a major challenge to international harmonization of animal health disinfectant standards. The disinfectant testing situation is further complicated by overlap between the jurisdictions of the various agencies involved in the production, evaluation, licensing, testing and use of disinfectants and sanitizers.

Most tests for determining the efficacy of disinfectants against specific microorganisms are modelled on the phenol coefficient. This method was developed to evaluate the efficiency of chemicals against Salmonella typhosa, the causal agent of typhoid fever. Despite arguments over the applicability of this method to modern products and its apparent obsolescence in the face of current technology, the phenol coefficient or adaptations of the method are still used.

The phenol coefficient and a number of other methods for comparing germicidal activity have been periodically modified. Various versions have been endorsed by authorities and organizations such as the Association of Official Analytical Chemists. Most methods determine the ‘lowest concentration’ (most dilute solution) of a germicide which is capable of inactivating a specific pathogen under standard test conditions. This value is compared to standard compounds and a product dilution is determined which would be effective against the given bacteria under field conditions.

Testing disinfectants for virucidal properties is challenging, and to date no mutually acceptable methodology has emerged (7). Most disinfectants destroy cell cultures. Other biological reagents used in viral assays and mixtures of viruses and disinfectants must be diluted before testing. Thus, failure to detect residual virus does not necessarily eliminate the possibility of infective levels of contamination (4). For this reason, antiviral activity of disinfectants or sanitizers is frequently expressed as degrees of inactivation and reported as tenfold (log) reductions in virus titre on the surface tested.

In practical settings, these determinations are made using one of a number of techniques, as follows:

- bacteriological and fungal cultures using surface swabs or agar impressions
- virus isolation procedures or observation of susceptible sentinel animals
- quality assurance testing of food products at various stages in processing.
TYPES OF DISINFECTANTS USED IN ANIMAL DISEASE CONTROL PROGRAMMES

The many naturally-occurring or chemically-synthesized disinfectant compounds, mixtures and products in world-wide use are far too numerous to describe individually here. Lists of approved disinfectants and sanitizers rapidly become obsolete as new products appear. Brief descriptions are given below of compounds and common disinfectants historically or currently used in animal health applications. These include hot water, acid-anionic surfactants (substances that improve penetration by reducing surface tension), amphoteric surfactants, bromides, chlorides, chlorhexidine, iodides, phenolic compounds and quaternary ammonium compounds.

Water

Water is the most important element of the HACCP concept and of the cleaning and disinfection process. Although water is actually a cleaner rather than a disinfectant, hot water has major disinfecting applications. Hot water is sometimes the major component of cleaning and disinfection in abattoirs and food-processing plants, where chemical residues must be avoided. Hot water under pressure cleans by flushing and by hydraulic impact; it dissolves inorganic salts, emulsifies fats, washes away organic debris, and is briefly bactericidal until the surface cools. When used for cleaning, sanitizing or disinfecting, water must be of microbiologically acceptable quality, maintained at the desired temperature and applied in abundant quantities.

Hot water must be used with caution to avoid scalding workers or bystanders. Under excessive pressure, water produces pock-marks in concrete, and fractures in mortar, tiles and masonry grouting. These pock-marks and fractures create micro-ecosystems in which organic material may accumulate, and this material in turn may harbour bacteria.

Ammonium hydroxide

Ammonium hydroxide is effective against oocysts of Coccidia spp., which affect poultry and rabbits. This substance is not effective against most bacteria. To obtain reasonable antimicrobial coverage, use of ammonium hydroxide should be followed by general disinfection with a compound appropriate to the situation.

Calcium oxide

When mixed with water, calcium oxide (quicklime) becomes lime wash, which has biocidal effects on some bacteria and viruses but is not very effective against FMD virus. Sometimes, quicklime is spread on the ground after depopulation of infected premises, but the value of quicklime under these conditions has been questioned. Quicklime has also been used to retard putrefaction of buried carcasses after depopulation. In these situations, it probably has little direct effect on FMD virus.

Chlorine disinfectants

Chlorine is usually found in nature in combination with other elements. It has bleaching and germicidal properties and is commonly used in disinfection, sanitizing and water purification. In high concentrations, chlorine is used for sewage treatment. Chlorine disinfectants and sanitizers are readily available, inexpensive, have a broad antimicrobial spectrum and present minimal environmental hazards. Aqueous chlorine solutions (obtained by dissolving hypochlorites) are rapidly bactericidal and exert virucidal effects via mechanisms which have not yet been completely explained but which are probably related to the destruction of essential enzyme systems.
In solution, chlorine (an oxidizing agent) reacts readily with metallic ions, various radicals and organic materials. After these reactions, the remaining active chlorine rapidly interacts with pathogens in a disinfecting capacity. Aqueous chlorine disinfectants have largely been replaced by organic chlorine compounds.

Bacteria, viruses and spores vary in their relative resistance to chlorine disinfectants (4). Protozoa also have varying sensitivities; for example, *Giardia* spp. are affected but not *Cryptosporidium* spp. Chlorine disinfectants are very effective in the absence of organic material. Other factors affecting the efficacy of chlorine-based disinfectants are concentration, pH, presence of natural proteins and presence of ammonia (a major component of animal urine).

Hypochlorites are still commonly used in animal health programmes. They include sodium hypochlorite (obtained by electrolysis of salt) and calcium hypochlorite (chlorinated lime, bleaching powder or chloride of lime). Hypochlorites have broad spectrums of antibacterial and antiviral action, and are compatible with most detergents. However, these substances are corrosive, are easily neutralized by organic material and decompose readily. Chlorinated lime – a hygroscopic white powder containing a variety of calcium and chlorine compounds – is frequently sprinkled in barnyards and on piles of manure, the released chlorine serving as a general disinfectant.

**Chlorhexidine**

Chlorhexidine and its analogs are commonly used at concentrations below 4% as skin cleaners, teat dips and antiseptics; they are also used for cold sterilization of surgical instruments and for disinfecting equipment, barns and buildings. While chlorhexidine is not sporicidal, it is useful against fungi, Gram-positive bacteria and, to a much lesser extent (4), against viruses and Gram-negative bacteria (some of which are resistant to chlorhexidine). Chlorhexidine retains some activity in the presence of small amounts of uncontaminated organic material (e.g. milk, serum or fish meal) but is ineffective when gross faecal contamination is present. The low toxicity of chlorhexidine makes it useful in combination with other disinfectants. Chlorhexidine has broad applications in cleaning dairy equipment and in aquaculture.

**Iodine and iodine-based disinfectants**

Many forms of iodine find common use in animal health and food-processing disinfection. In nature, iodine is always found in combination with other elements. It is present at high levels in seaweed, which is the most common commercial source; iodine is also found in extractable levels in sea water and other brines, and in nitrate deposits (where it exists as iodates). In the pure state, iodine is a soft black crystalline solid. Low levels of iodine are essential to mammalian life, and deficiency results in goiter. In great excess, iodine can cause acute or chronic toxicity. Aqueous iodine (Lugol's solution) or alcoholic iodine solutions (tinctures of iodine) are commonly used as antiseptics.

Iodophors are disinfectants formed by combinations of iodine with various carrier compounds. These release iodine in an acid medium and have disinfectant properties which affect bacteria, viruses and some spores (13). Iodophors are used for general disinfection and cleaning, bovine teat dips, and surgical scrubs. Hard water and the presence of large amounts of organic material reduce the activity of iodophors, but these disinfectants can function effectively in the presence of traces of organic material.

**Quaternary ammonium compounds**

Quaternary ammonium compounds (QACs; also called 'quats') are natural biochemicals involved in the transmission of neuromuscular impulses in mammals.
Synthesized QACs are surface-active cations which have sanitizing/disinfecting and mild detergent actions. They act as one-step cleaner/sanitizers in aqueous solution or when combined with detergents. QACs are generally more effective in slightly alkaline media. They are widely used in medical facilities, in food-processing and food-handling establishments, and in agricultural settings. In appropriate dilutions, QACs are effective, non-toxic, biodegradable disinfectants. Even in the presence of hard water and/or moderate amounts of organic material, they have a broad spectrum of antibacterial, antifungal, antiviral and sporidal activities. QACs lack efficacy against Mycobacterium tuberculosis.

New generations of QACs continue to be developed, and each successful modification of the basic benzalkonium chloride prototype seems to offer new advantages in safety, cleaning power and disinfectant properties. Currently, QACs are the disinfectants of choice in a number of animal health applications. When used in recommended concentrations, they are tasteless, odourless and virtually non-toxic. However, they cause conjunctival irritation if applied directly to the eyes. Some workers in daily contact with QACs develop a contact dermatitis which may be a hypersensitivity reaction.

**Sodium hydroxide**

In the 1930s, sodium hydroxide (lye, caustic soda or soda ash) in a 2% solution was the recommended disinfectant for anthrax; 2% lye was also formerly used to disinfect equipment, animal conveyances, surfaces and water-resistant clothing when FMD was diagnosed. In this concentration, sodium hydroxide is also effective against many other viral and bacterial diseases, and has been used against fowl cholera and pullorum disease (12). It has been largely replaced with less corrosive and less irritating modern disinfectants. However, in emergencies sodium hydroxide can still be an option, as it is readily available and extremely effective.

In early times, lye was obtained by leaching wood ash in water. The early product probably contained some potassium hydroxide (potash) and other contaminants found in impure soda ash. Pure sodium hydroxide is now commercially available in most countries, as it is commonly used in the chemical and paper industries, and as a septic line cleaner. It should be used with extreme caution and under well-controlled conditions, due to the corrosive and irritating properties, and potential dangers to the environment and to workers. When applying lye, workers should wear waterproof coats and hats, boots and goggles; aluminium surfaces should be protected from contact with the lye, and users should be aware that it will remove paint.

**Phenolic compounds**

Many phenolic compounds may be obtained from numerous sources by a wide variety of processes. Pure phenol (carbolic acid) is rarely used in disinfection. However, related compounds are common components of disinfectants and are frequently used in disinfection of horse facilities. These mixtures are regarded as general disinfectants. Although some synthesized phenol compounds are odourless, many phenolics have the characteristic odour traditionally associated with disinfectants. Sometimes, the odour persists and serves as a biosecurity reminder long after the disinfectant capacity has been exhausted. This can happen with foot baths at the entrances of animal facilities, when the contents are not replenished regularly and become heavily contaminated with manure and bedding.

The coal tar-derived phenols are distillates of heated coal, and are similar to the pine tar compounds derived by distillation of pine trees. Pine oil is considered separately
below. Many phenolic compounds in use today are synthesized, and these are purer and less pungent than earlier coal tar distillates. They are effective against both Gram-negative and Gram-positive bacteria, yeasts, fungi and some viruses. Synthetic phenols are usually ineffective against bacterial spores.

The antiviral activity of different phenols varies. In general, enveloped and naked lipophilic viruses are more susceptible to these disinfectants. Unlike most other phenols, the 2-phenylphenols are effective against the tubercle bacilli. Although the strong odour produced by phenols serves as a warning of their deteriorating effect on plastics and rubber, their extremely irritating qualities and their toxicity, it is of the utmost importance to emphasize that phenols can be fatal if swallowed and that toxic doses can be absorbed through the skin. Swine and cats are particularly sensitive to the phenols and even small doses can be fatal (12). Nonetheless, these are commonly-used and highly-effective general disinfectants.

The bisphenols, formed by linking two phenol molecules, are more effective than the simple phenols and have improved bactericidal and bacteriostatic properties. The discovery of the bisphenols led to the synthesis of hexachlorophene and a new generation of antiseptic/sanitizers.

Pine oil

Pine oil, which was historically obtained by distillation of pitch-filled pine wood, cones or needles, is now prepared synthetically. Pine oil is a clear, colourless or amber-coloured liquid, with a characteristic odour which is more pleasant than that of coal tar-derived creosote compounds. It is insoluble in water if used alone, and is therefore usually emulsified with soaps, or mixed with detergents or other compounds. Pine oil is more effective as a general disinfectant when applied hot (17). Wood-origin pine oils have now been largely replaced by mixtures in which commercially-synthesized chlorinated phenols perform the principal disinfectant activity. In these mixtures, pine oil is a relatively inactive ingredient, contributing mainly to the characteristic disinfectant odour.

Longstanding uncertainty exists with regard to the antimicrobial efficacy of pure pine oil. In mixtures, it may be a valuable hygienic adjunct, if only for the warning created by its characteristic smell.

Inorganic acids

The inorganic acids most commonly used in animal disease control are sulfuric acid and hydrochloric acid. Both of these are effective against FMD virus but are also highly toxic if swallowed, highly irritating to the skin and eyes, and very corrosive to metals. Thus these acids are used only in very limited situations.

Organic acids

A number of organic acids with bactericidal and mild viricidal properties have disinfectant applications in animal health and food processing, as they are less toxic and less corrosive than the inorganic (metallic) acids mentioned above. Acetic acid is readily available, being present (4%) in vinegar. At 2%, acetic acid can significantly reduce levels of FMD virus on contaminated surfaces, and is used to reduce bacterial levels in meat packing plants. Acetic, citric, lactic, formic and propionic acids are sometimes used in meat and poultry packing plants, and in calf and pig barns. These acids have also been added to animal feeds to reduce levels of Salmonella contamination (15).
Formaldehyde

The natural form of formaldehyde is a gas. However, formaldehyde is more readily available as a 40% aqueous solution called ‘formalin’. Gaseous formaldehyde is used for the fumigation of buildings, rooms or vehicles which can be sealed. Fumigation with formaldehyde is effective against most viruses and bacteria, including the acid-fast Mycobacteria.

Formaldehyde gas is relatively unstable and can sometimes explode. It is difficult to achieve an even distribution and penetration of formaldehyde gas throughout buildings, which may lead to incomplete effect (13). For formaldehyde fumigation to be complete, the temperature must be above 55°F (13°C) and relative humidity must be above 70%. Spraying with hot water is sometimes necessary to achieve these conditions. For fumigation purposes, formaldehyde gas can be produced by oxidizing formalin with potassium permanganate, by heating paraformaldehyde, by mechanically generating a mist of formalin, or by applying complex mixtures from which formaldehyde is slowly released after application. Formaldehyde fumigation is hazardous and must be carefully supervised; details of its use are outlined elsewhere in this issue of the Review (2, 11, 29).

A 1-5% formalin solution is sometimes used to disinfect buildings or as a prophylactic and therapeutic foot bath for foot rot in sheep and cattle. The use of formaldehyde in disinfectant situations is declining, due to the strong, irritant odour, corrosiveness, fibrolytic properties and toxicity. The use of formaldehyde may soon become illegal in some countries due to environmental concerns. Thus ozone, bromides and other fumigants are being studied as alternatives (32).

Glutaraldehyde

Glutaraldehyde, which has been used for cold liquid sterilization of surgical instruments, is sometimes still used to disinfect surfaces. As with formaldehyde, the use of glutaraldehyde is diminishing in favour of newer products.

Sodium carbonate

Sodium carbonate, also known as washing soda, has been used in a hot solution (180°F [82°C]) for disinfecting buildings which have housed animals with FMD. This substance lacks efficacy against some bacteria and most viruses, including Newcastle disease virus. Sodium carbonate is more effective as a cleanser than as a disinfectant.

**SPECIFIC CONSIDERATIONS FOR DISINFECTANT APPLICATIONS**

Different disinfection procedures will be appropriate in specific situations. Disinfection of animal housing (13, 25) usually involves the following steps:

- remove all animals, utensils and equipment
- scrub, scrape and flush away all gross organic material using a cleaner/sanitizer or detergent compound
- rinse thoroughly
- apply the chosen disinfectant and leave this in contact with surfaces for as long as possible
- rinse thoroughly
- leave the facility free of animals for an effective time interval.

**Use of disinfectant foot baths and wheel baths**

Disinfectant foot baths are commonly placed at doorways of animal quarters, sales barns, quarantine stations and research facilities to help exclude infectious agents and prevent the exit of microorganisms. Foot baths are most effective when properly filled and frequently replenished with appropriate products, and when users wear rubber footwear which can be soaked for several minutes. If these conditions are not fulfilled, foot baths probably serve more as biosecurity reminders than as effective disease control mechanisms (25).

Disinfectant foot baths can be effective if refilled every 2-3 days, appropriately situated (e.g. sheltered from rain or snow which would dilute the disinfectant) and protected from freezing. In locations where foot baths may freeze, these should be heated, as the addition of antifreeze or salt may inactivate the disinfectant. If the feet of users are soiled with manure, bedding, mud or other debris, a foot bath should be provided for washing boots before soaking them in the disinfectant. These same guidelines apply to wheel baths through which trucks are driven when entering and leaving premises. For further details on the preparation and use of foot baths and wheel baths, readers are referred to the paper by Fotheringham on ‘Disinfection of livestock production premises’ (11).

**Pre-disinfection considerations**

Before the commencement of pre-disinfection cleaning, the location and ownership of premises should be specified. The goals of the disinfection operation and the plan of action must be written out. Then, in consideration of the goals of the disinfection, the type of material being disinfected and the suspected contaminating organisms, a disinfectant can be chosen which best suits the situation, while providing optimum safety for animals, humans, equipment and the environment. The chosen product must be effective against the organism in question and must be approved for use by national regulatory officials.

In addition to choosing a disinfectant with an appropriate antimicrobial spectrum, the zoonotic potential of suspected contaminating organisms as possible hazards to the disinfecting crew and other workers should be evaluated. Pre-planning should also consider the toxic potential of the disinfectant, as well as irritant properties for skin and eyes, corrosiveness, paint-removing capabilities, and potential damaging effects on wood, metal, fibres, concrete, rubber or electrical outlets. If the suspected contaminating organism is exotic or has zoonotic potential, or if the disinfectant has toxic, irritant or corrosive properties, then protective clothing, masks and rubber footwear must be worn.

The drainage of the site and disinfectant run-off must be considered with respect to the proximity of waterways and wells and possible contact with humans, wildlife, livestock or poultry. As outlined elsewhere in this issue of the *Review* (5, 23), the local wildlife, bird and rodent populations must be surveyed, to determine if infection exists among susceptible species or if they can serve as mechanical or biological vectors of relevant pathogens. The disinfected area must be sealed to prevent wild fauna from entering. The local ecosystem must be assessed to determine the appropriateness of carcass disposal by burning, burial or composting.
Disinfection while animals are still present

If circumstances require that animals remain in the area to be disinfected, or in contiguous areas, this will have a significant impact on the pre-disinfection process, the disinfectant product chosen and the method of application. In such circumstances, complete cleaning prior to disinfection is impossible, and the disinfectant product used must be non-toxic and must have biocidal effects when applied as a mist or aerosol. Chemicals which function well in this mode include the o-phenylphenols, hexylresorcinol, resorcinol, chloroxyphenol, propylene glycol and trimethylene glycol. If at all possible, such applications should be avoided in favour of all-in/all-out management practices, where disinfection is conducted during the 'down time' (when buildings are unoccupied).

Pre-disinfection cleaning

Pre-disinfection cleaning is the most crucial element in the disinfection process, and will probably eliminate the majority of microorganisms if performed well (13, 25). Pre-disinfection cleaning requires the removal of all animals. Manure, litter and bedding must be removed and buried, burned or composted, depending on the situation. Disinfection of these materials is discussed by Haas et al. (14).

Any movable equipment and utensils must be removed and individually cleaned, scrubbed and rinsed. All surfaces of the facility should be moistened with water to prevent excess dust from arising during the vigorous cleaning process. If zoonotic diseases are suspected, an appropriate disinfectant should be used for wetting down prior to disinfection, and workers should be required to wear masks and protective clothing. All faeces, dirt, dust, mud or other material should be removed by scraping, sweeping, scrubbing or flushing with high-pressure water.

The facility should then be hosed down using a detergent soap or sanitizer, or a classic disinfectant/cleaner (e.g. 2-4% sodium carbonate solution) which must be completely flushed away to prevent this reducing the efficacy of the disinfectant to be subsequently applied.

Disinfection process

Prior to application of the disinfectant product, all traces of the material used in the pre-disinfection process must be flushed away with water to avoid diluting, neutralizing or inactivating the chosen disinfectant. The users must read the entire product label and follow the dilution instructions explicitly to ensure that the safest, most effective concentration is applied.

The disinfectant is then applied to every surface and recess, starting at the highest point and working downwards. During this process, the health status of the personnel applying the disinfectant and any bystanders must be under constant observation, and there must be continual alertness for run-off heading in unexpected directions.

The disinfectant must be left on surfaces for as long as possible (at least as long as indicated in the instructions). The area must then be thoroughly rinsed and left vacant for as long as possible before post-disinfection samples are collected and/or sentinel animals positioned.

Re-stocking with healthy, uninfected animals should only be undertaken when post-disinfection tests and/or sentinel animal evaluations reveal that the premises have a low probability of harbouring residual pathogens.
Causes of disinfection failure

Possible causes of disinfection failure include the following:
- over-dilution of disinfectant during pre-mixing or application
- incomplete or inadequate cleaning
- poor disinfectant penetration or coverage
- insufficient contact time on surfaces
- inadequate temperature and humidity while the material is being applied.

Failure can also result from inactivation or neutralization of the disinfectant, due to the presence of residual cleaning liquids which were not adequately flushed away before the disinfectant was applied. A common mistake is to select a product which is ineffective against the contaminating organisms present (or suspected). The entire process must be repeated if examination of sentinel animals or laboratory tests on environmental samples indicate that pathogens have survived the procedure.

Finally, one frustrating cause of apparent disinfection failure is invalidation of the entire process when disease is re-introduced by re-stocking with infected animals.

PREPARING DISINFECTANT PROTOCOLS, REQUIREMENTS AND REGULATIONS

Regulations, requirements and protocols for disinfection should be consistent with the laws of the promulgating nation. They must have a sound technical basis, and should be clear and easily explained; they must be more than bureaucratic requirements put forward to demonstrate power or to keep people busy.

Under international trade agreements, sanitary and phytosanitary requirements must have a true health basis and must not serve as non-tariff trade barriers. Such requirements must be scientifically and environmentally sound, and must be clearly outlined in regulations; practical implementation and professional regulatory supervision must be feasible given the existing animal health infrastructure and regulations of the country or region.

Required products and procedures should be effective against the organisms towards which they are directed. Thorough cleaning by flushing with water should always precede application of disinfectants. Some form of inspection and post-disinfection testing should always be included in the certification procedure.

Disinfectant certification

Certificates of disinfection required by regulatory agencies can take a variety of forms. The minimum required information includes the following:
- location and ownership of the facility disinfected
- date, nature and extent of pre-disinfection cleaning
- target microorganisms
- name, active ingredients and concentration (dilution) of the chemical used
- ambient or surface temperature during application
- contact time of the disinfectant with the treated surface
- names of personnel applying the disinfectant, and inspectors.
Disinfection checklist

The checklist presented in the Appendix indicates items to be considered in ensuring responsible disinfectant use in regulatory programmes, or in routine animal health or food-processing applications. This list can be adapted to specific situations and modified to conform with national, international and regional standards and regulations. It provides supervisors and disinfectant users with a framework for reviewing crucial items, and raises questions which might otherwise be overlooked in the urgency of day-to-day activities.

The use of this checklist in planning, executing, documenting and evaluating disinfection activities will increase efficacy and ensure compliance with health, safety and environmental regulations, and satisfaction of current public concerns.

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Appendix

Disinfection checklist

This checklist presents the factors which must be considered and documented in planning, implementing and evaluating any disinfection procedure.

Area, premises and facility data
- Ownership
- Location, address
- Function of facility
- Type of facility: building, truck, aircraft, ship, other

Legal considerations
- Authority for disinfections
- Permission of owner
- Local and national laws applicable

Environmental factors
- Urban or rural setting
- Terrains
- Drainage
- Livestock populations
- Wildlife populations
- Vector populations
- Nearest waterway
- Nearest wells, reservoirs, water sources
- Nearest dwellings
- Nearest livestock or poultry
- Environmental safety factors

Objectives of disinfection
- Focused disinfection
- Organisms of concern
- General disinfection
- Post-depopulation disinfection
Pre-disinfection cleaning
- Animal removal
- Removal and disposal of manure and litter
- Electronic equipment protected
- Electricity switched off
- Physical cleaning method
- Pre-cleaning dampening
- Method of water application
- Check surface and underground drainage of pre-cleaning water
- Post-cleaning inspection
- Post-cleaning drying period

Disinfectant product data
- Product name
- Product manufacturer
- Product licensed or approved in country and region
- Active ingredients
- Entire label read by applicators and supervisors
- Label safety precautions
- Label residue precautions
- Other products used or combined/mixed
- Dilution rate
- Final concentration
- Temperature of diluent
- Product toxicity; oral, skin and eye contact
- Product carcinogenic
- Corrosive to aluminum, paint, concrete, rubber, plastic
- Other

Safety data/protection of personnel
- Zoonotic potential of environment
- Protective clothing, boots, raincoats, goggles, hats
- Other

Safety data/environmental hazards
- Hazards to livestock, poultry
- Hazards to wildlife
- Hazards to waterways and aquifers
- Environmental regulatory approval

Disinfection application data
- Names of personnel applying disinfectant
- Date of application
- Duration of application
- Weather during application
- Ambient temperature
- Disinfected area sealed to exclude birds, rodents, wildlife
- Temperature variations from ambient
- Application pressure
- Duration of surface contact
- Post-application walk-through
Post-disinfection data
- Post-application inspection
- Post-application samples sent to laboratory
- Sentinel animal observations
- Test re-stocking
- Issue certificate of disinfection.

REFERENCES


