



Lowering Infection Rates in Hospitals and Healthcare Facilities

The role of copper alloys in fighting infectious organisms

Copper alloys and the fight against pathogens

The results of recent research suggest that copper alloys with antimicrobial properties can be used for surfaces exposed to human touch or contact with food and can contribute to a reduction in the transmission of human pathogens.

Copper Development Association aims to inform regulatory bodies, healthcare facilities, manufacturers, architects and other stakeholders about ongoing scientific and regulatory developments in the marketplace and the benefits that can be derived from the use of copper alloys.

Supported by its members, Copper Development Association hopes to be a catalyst in the development of a healthier environment in healthcare facilities.

Copper Development Association

Copper Development Association provides information on copper's properties and applications, essentiality for health, role in technology and the quality of life. The Association also provides a link between research and the user industries and maintains close contact with the other copper centres throughout the world. Copper Development Association, along with 10 other centres in Europe, is a member of the European Copper Institute.

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Naturally Antimicrobial. Copper

An introduction to the efficacy of copper in battling infectious organisms

Many bacteria, known to be human pathogens, cannot survive on copper alloy surfaces. The number of live bacteria drops from several orders of magnitude to almost zero on copper alloys in a few hours. In marked contrast, virtually no reduction in the number of the same harmful pathogens is seen on stainless steel during a six-hour test period.

Copper alloys which have been tested include high coppers, brasses, bronzes, copper-nickels and copper-nickel-zincs. The bacteria tested include Methicillin-resistant *Staphylococcus aureus* (MRSA), the cause of serious hospital-acquired infections, *Pseudomonas aeruginosa*, *Enterobacter aerogenes* and *Acinetobacter baumannii* as well as *E. coli* O157:H7 and *Listeria monocytogenes*, foodborne pathogens associated with several large-scale food recalls.

The results of these studies suggest the selection of copper alloys for surfaces exposed to human touch or food contact. Using copper alloys in this manner can materially assist in reducing the transmission of potentially infectious organisms.

Source: Abstract from 'Copper Alloys for Human Infectious Disease Control' by H T Michels, S A Wilks, J O Noyce and C W Keevil.

Foreword

In this booklet, a strong case is presented for the value of copper and copper alloys to help control the incidence of infection from cross-contamination due to dangerous foodborne and hospital-borne pathogens, such as *E.coli* O157, *Campylobacter*, *Listeria monocytogenes*, *Salmonella* and the difficult-to-treat Methicillin-resistant *Staphylococcus aureus* (MRSA). This case is based on copper's intrinsic ability to quickly inactivate (destroy) these dangerous microbes at both refrigerated temperature (4°C) and at room temperature (20°C).

The objective of the European Copper Institute's Biohealth Initiative is to promote the benefits of copper alloys for the inactivation of harmful bacteria on surfaces exposed to human touch or food contact. This is consistent with our vision to inspire the world about copper's essentiality for health, technology and the quality of life.

The Biohealth Initiative supports the development and exchange of information, experience, expertise and ideas that will meet the scientific, commercial and regulatory needs of all stakeholders.

John Schonenberger

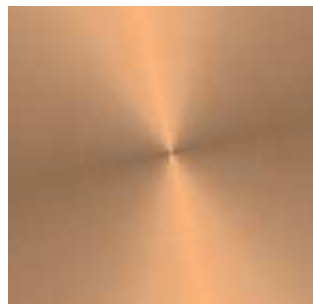
Chief Executive
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Copper and Copper Alloys

Copper is number 29 in the periodic table of elements. As the first element in the group containing silver and gold, it is considered a semi-precious metal. Copper and its alloys offer a wide range of properties to meet the needs of many applications which humans touch. The list is almost endless and is limited only by the knowledge, creativity and imagination of those who specify, design, produce and process copper-based products.



Pure copper

Copper is refined from ore and shipped to fabricators mainly as cathode, wire rod, billet, cake (slab) or ingot. Through extrusion, drawing, rolling, forging, melting or atomisation, fabricators form wire, rod, tube, sheet, plate, strip, castings, powder and other shapes. These copper and copper-alloys are then shipped to manufacturing plants where they are used to make products to meet society's needs.

Properties of copper

These unique properties account for copper's widespread and long-term use as an industrial material:

- Melting point of 1083°C (1981°F)
- Metallic lustre and reddish colour
- High electrical and thermal conductivity
- Non-magnetic
- Alloys readily available as both a solute (copper as an alloying element) and a solvent (copper containing other alloying elements)
- Good corrosion resistance and durability
- Forms a protective oxide in air and water
- High malleability, formability and ductility
- Good machinability
- Readily electroplated
- Essential nutrient for life
- Highly recyclable

Copper alloys

Copper alloys are described generically by such terms as brass, bronze, copper-nickel and copper-nickel-zincs, which are called nickel silvers because of their shiny white colour, even though they contain no silver.

Copper alloys are widely used in many applications ranging from electrical wiring and connectors to musical instruments, from household plumbing tube and fittings to keys, locks, door knobs, coins and handrails. The applications are almost endless. The wide use of copper alloys is attributable to a long history of successful use, ready availability from a multitude of sources, the attainability of a wide range of physical and mechanical properties and amenability to subsequent processing such as machining, brazing, soldering and polishing.



The properties of copper alloys, which occur in unique combinations found in no other alloy system, include high thermal and electrical conductivity, a wide range of attainable strengths, excellent ductility and toughness, as well as superior corrosion resistance in many different environments.

Properties of copper alloys

Good corrosion resistance — Contributes to durability, and leads to long-term cost-effectiveness.

Favourable mechanical properties — Ranges from pure copper, which is soft and ductile, to alloys such as the manganese bronzes, which can rival the mechanical properties of quenched and tempered steel. Almost all copper alloys retain their mechanical properties, including impact toughness, at very low temperatures.

High thermal and electrical conductivity — Copper has higher conductivity than any other metal except silver. Conductivity drops when copper is alloyed. However, even copper alloys with relatively low conductivity transfer both heat and electricity far better than other corrosion-resistant materials such as titanium, aluminum and stainless steel.

Biofouling resistance — Copper inhibits the growth of marine organisms, including algae and barnacles. This property, unique to copper, decreases when alloyed. However, it is retained at a useful level in copper alloys, such as the copper-nickels routinely found in marine applications.

Antimicrobial action — Copper chemicals have been used historically as bactericides, algacides and fungicides. However, recent studies indicate that bacteria, including certain harmful strains of *E. coli* and MRSA or *Methicillin-Resistant Staphylococcus aureus*, serious nosocomial or hospital-acquired infections, simply die in a few hours when placed on copper alloy surfaces at room temperature.

Low friction and wear rates — Copper alloys, such as the high-leaded tin bronzes, are cast into sleeve bearings and exhibit low wear rates against steel. Nickel bronze and tin bronze are the industry standards for worm gears, an application in which low wear rates are important.

Good castability — All copper alloys are sand castable and almost all can be centrifugally and continuously cast. Many can be permanent moulded and precision-

or die-cast. Wrought copper alloys are initially cast and subsequently hot and cold rolled.

High fabricability — Copper alloys are readily hot rolled, extruded or forged. They then may be cold rolled to the desired thickness. Sheet, plate, strip and bar products are readily forged, stamped and bent into desired shapes.

High machinability — Good surface finish and high tolerance control is readily achieved. While leaded copper alloys are free-cutting at high machining speeds, many unleaded alloys, such as nickel-aluminum-bronze, are readily machinable at recommended feeds and speeds with proper tooling.

Ease of subsequent processing — Many copper alloys are routinely polished to a high lustre, especially those with an aesthetically pleasant colour, such as the gold-coloured brasses. Plating, soldering, brazing and welding are also routinely performed.

Availability of a range of alloys — Any of several alloys may be suitable candidates for given applications, depending on design loads and corrosivity of the environment.

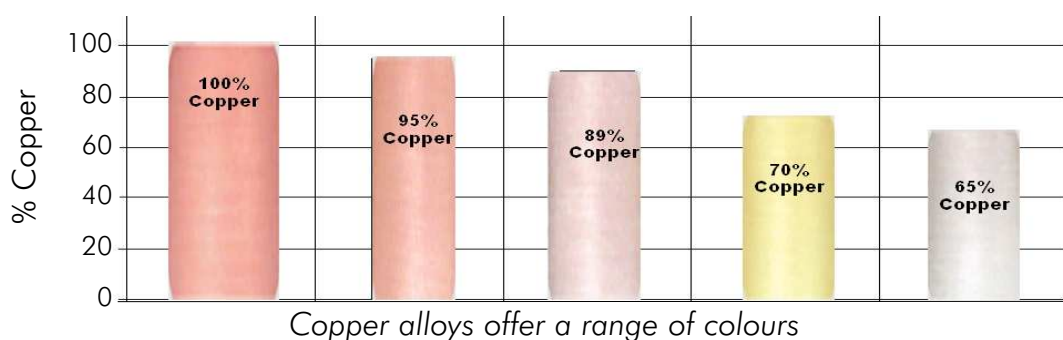
Reasonable cost — High processing yield and low machining costs makes copper alloys very economical. Gates and risers from castings and swarf from machining are recycled, which leads to additional cost reductions. In addition, copper alloys do not require surface coatings, which further reduces initial costs and provides additional maintenance savings. When a component reaches the end of its useful life, it too is readily and routinely recycled.

Aesthetically appealing — Copper and its alloys are available in a wide range of warm colours and finishes suitable for interior applications.

Recyclability — Copper and its alloys have an infinite recyclable life. Copper has the highest recycling rate of any engineering metal. In fact, 41% of our European copper demand is met from recycling.

Copper alloy products are:

- Readily manufactured
- Homogenous and solid
- Durable
- Available in a range of colours
- Cost-effective
- 100% recyclable



The Antimicrobial Properties of Copper

Copper utensils, cookware and drinking water containers have been used to prevent the spread of disease since the early Roman Empire. Sometime later, scientists began to consider how copper's antimicrobial properties could be harnessed to provide additional benefits.

Over the years, scientists have determined that:

- copper, in very small quantities, has the power to control a wide range of fungi, algae and harmful microbes.
- copper is antimicrobial in aqueous and humid-air environments.
- copper has wide-ranging possibilities as a disinfectant.

Today, the antimicrobial uses of copper have been expanded to include fungicides, antifouling paints, antimicrobial medicines, oral hygiene products, hygienic medical devices, antiseptics and a host of other useful applications.

For many years, scientists have attempted to decipher the precise chemical and molecular mechanisms responsible for copper's antimicrobial property. They have found copper's antimicrobial mechanisms are very complex and take place in many ways, both inside cells and in the interstitial spaces between cells. The main hypotheses are:

- Elevated copper levels inside a cell cause oxidative stress and the generation of hydrogen peroxide. Under these conditions, copper participates in the so-called Fenton-type reaction — a chemical reaction causing oxidative damage to the cell.
- Excess copper causes a decline in the membrane integrity of microbes, leading to leakage of specific essential cell nutrients, such as potassium and glutamate, and subsequent cell death.
- While copper is needed for many protein functions, in an excess situation (as on a copper alloy surface), copper binds to proteins that do not require copper for their function. This 'inappropriate' binding leads to loss-of-function of the protein and/or breakdown of the protein into non-functional portions.

These possible mechanisms, and others, are the subject of continuing study by the Copper Development Association and the International Copper Association.

Antimicrobial copper inhibits cross-contamination in:

Food-processing facilities

Copper and copper alloys have been proven to eliminate foodborne microbes at room and chill temperatures — while stainless steel, the most common touch surface material in the food processing industry, has been found to have virtually no efficacy in destroying pathogenic microbes.

Since processed foods are frequently in physical contact with various touch surfaces during processing, it is imperative that these surfaces do not facilitate the spread of pathogenic contaminants. It would be of even greater benefit if these touch surfaces had inherent antimicrobial properties that could quickly and effectively destroy foodborne pathogens.

Health-related facilities

During the past 20 years, inadequate hygienic practices in health-related facilities have resulted in a dramatic increase in the incidence of hospital-acquired infections around the world. In addition to threatening lives, HAIs are a huge financial burden on a nation's healthcare system. Furthermore, few prospective antibiotics are in the pipeline to combat resistant strains of microbes.

Key scientific investigations have demonstrated the efficacy of copper and copper alloys to inactivate hospital-borne microbes, including Methicillin-resistant *Staphylococcus aureus* (MRSA).

Hence, there is a possibility that numerous touch surfaces at health-related facilities could be replaced with copper alloys to help reduce the incidence of microbial infection due to cross-contamination.



Nick Yardsley, Wizwam

Copper is also Essential for Humans, Animals and Plants

Copper is an essential micronutrient

Because it is an essential element, various national and international health agencies, like the World Health Organisation, recommend a minimal acceptable copper intake of approximately 1.3 mg/day. The recommended intake for healthy adult men and women in North America is 0.9 mg/day, according to the Food and Nutrition Board of the National Academies of Science in the USA. It suggests adequate dietary reference intakes (DRIs) for copper at 0.3 mg/day for children of 1–3 years, 0.4 mg/day for 4–8 years, 0.7 mg/day for 9–13 years, and 0.9 mg/day for 14 years and older.

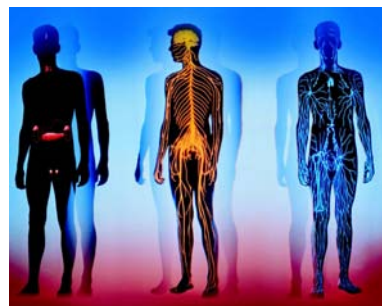
Copper is necessary for the growth, development and maintenance of bone, connective tissue, brain, heart and many other body organs. It is involved in the formation of red blood cells, the absorption and utilisation of iron and zinc, and the synthesis and release of life-sustaining proteins and enzymes. These enzymes produce cellular energy and regulate nerve transmission, blood clotting and oxygen transport.

Copper is also known to stimulate the immune system, repair injured tissues and promote healing. More recently, copper has been attributed to helping neutralise 'free radicals' which can cause severe damage to cells.

Copper and the very young

Copper is essential for the normal growth and development of human foetuses, infants and children. The human foetus accumulates copper from its mother during the third trimester of pregnancy, apparently to ensure that it will have adequate supplies to carry out metabolic functions after birth.

In infants and children, copper deficiency may result in anaemia, bone abnormalities, impaired growth, weight gain, frequent infections (colds, flu and pneumonia), poor motor coordination and low energy. To protect infants from copper deficiency, pregnant and nursing women should, under a doctor's supervision, increase their dietary intake of copper.



Dietary copper deficiency

The World Health Organisation estimates at least 20% of the world's population suffers from health disorders associated with dietary copper deficiency. Symptoms may include osteoporosis, osteoarthritis and rheumatoid arthritis, cardiovascular disease, colon cancer and chronic conditions involving bone, connective tissue, heart and blood vessels. Even mild copper deficiency, which affects a much larger percentage of the population, can impair health in subtle ways. Symptoms of mild copper deficiency include lowered resistance to infections, reproductive problems, general fatigue and impaired brain function.

Pregnant mothers who are severely deficient in copper could increase the risk of health problems in their fetuses and infants. These problems include low birth weight, muscle weakness and neurological problems.

Dietary sources of copper

The best dietary sources of copper include seafood (especially shellfish), organ meats (such as liver), whole grains, nuts, raisins, legumes (beans and lentils) and chocolate. Other food sources that contain copper include cereals, potatoes, peas, red meat, mushrooms, some dark green leafy vegetables (such as kale) and some fruits (such as coconuts, papaya and apples). Tea, rice and chicken are relatively low in copper but provide a reasonable amount of copper because they are, generally, consumed in significant amounts.

Eating a balanced diet, with a range of food from different food groups, is the best way to avoid copper deficiency.

Current Applications for Hygienic Copper

Agricultural applications

In the past, usage of copper compounds inhibited seed-borne fungi. Today, due to copper sulphate applications, this seed-borne disease is no longer an economic problem.

Copper fungicides are indispensable all over the world. Many plant diseases are prevented with small amounts of copper. Modern copper formulations, such as copper- δ -quinolate, copper octoate, nanocopper oxide, alkaline copper quat and copper azole, are now used to fight fungi in crops, textiles, paints and woods.

Antifouling surfaces and paints

Microbiologists and cell culture scientists rely on copper-walled incubators to resist microbial growth, particularly fungal growth, and to resist contamination of sensitive human and animal cell lines when they are being cultured in humidified laboratory incubators.

Copper's potent antifouling properties help to control unwanted organisms in fish farming. Antifouling copper-based paints are able to reduce bacterial populations by 99.9975% within 24 hours (Cooney and Kuhn, 1991). The antifouling benefits of copper sheathing on offshore platforms, on the bottom of boats and of copper-based paints for the marine environment, have been known for years.

Consumer products

Consumer products made with antimicrobial copper have been used in kitchen environments for a very long time. Copper scrubbing products are said to help prevent the cross-contamination of pots and pans. Copper sink strainers are commonplace in many regions, especially in Japan. In the Middle East, tabletops and water storage vessels have been made from copper for centuries.

Copper is also used for its bactericidal properties in medicines and hygienic products, such as antiplaque agents in mouthwashes and toothpastes. In India, copper tongue scrapers are used to control bad breath resulting from mouth bacteria and, in rural areas, traditional brass or copper vessels, muktas, are used for purification of drinking water.



Toxic Microbes in Healthcare Facilities

In the 1850s, some 50 years before scientists understood that a world of microbes was responsible for many diseases, the highly respected nurse, Florence Nightingale, discovered that her patients fared much better when the hospital environment in which she worked was clean.

She instituted a laundry service, rigorously cleaned all medical and hospital equipment, and 'had the floors in the hospital scrubbed for the first time that anyone could remember.' Nightingale's belief in what she considered to be 'common sense' cleaning measures reduced death rates of her patients from cholera, typhus and dysentery from 42% to a mere 2%.

One hundred and fifty years later, despite enormous advances in understanding pathogenic microbes and their role in hospital-acquired infections, hospital cleaning has been identified as an important (but often neglected) component of infection control.

Touch surfaces made from materials such as stainless steel or plastics have proven to be a significant source of cross-contamination, especially in healthcare environments. Regular disinfection of these surfaces is important and helpful, but it is often insufficient in stemming the growth and spread of pathogens.

In an effort to confront this situation, Copper Development Association Inc in the USA has submitted more than 300 copper alloys to the US Environmental Protection Agency

for registration as antimicrobial materials. Upon acceptance, the copper alloys would become the first materials in the USA ever allowed to make a public health claim for their antimicrobial properties. EPA's response is expected in late 2007.

Prior to the submission, more than 3,000 samples of five different alloys were subjected to three different EPA-mandated test protocols involving five different bacteria. The alloys, each containing 65% or more copper, represented the major alloy families.

Copper (C11000), brass (C26000), bronze (C51000), copper-nickel (C70600) and nickel-silver (C752000) successfully passed the prescribed tests against *Staphylococcus aureus* and MRSA (Methicillin-resistant *Staphylococcus aureus*), as well as *Enterobacter aerogenes*, *Pseudomonas aeruginosa* and *Escherichia coli* O157:H7.

The three test protocols consisted of a simple assay of remaining live bacteria after two hours on a copper surface, an inoculation of a copper surface followed by several wet and dry abrasions over 24 hours, and repeated inoculations on the same sample over 24 hours. All results were positive and consistent. In 174 of the 180 tests, the bacteria count was reduced by greater than 99.9%. In the remaining six tests, the bacteria count was reduced by between 99.3% and 99.9% — an amazing testament to copper's antimicrobial efficacy.

Other laboratory studies and clinical trials are being undertaken by the copper promotion network in the UK, US, Germany and Japan.

- Hospital-acquired infections affect 9 out of every 100 patients admitted to hospitals and result in nearly 5,000 deaths annually in England.
- Approximately 300,000 patients in the UK contract a nosocomial infection each year.
- According to the National Audit Office, hospital-acquired infections are a huge financial burden on the NHS, costing upwards of £1 billion per year.

MRSA: A Dangerous Threat is Prevalent in Hospitals

A worldwide overindulgence of antibiotic use has enabled many kinds of bacteria to become resistant to antibiotics. Penicillin, the first antibiotic miracle drug, and its stronger successors have been challenged in recent years.

A strain of *Staphylococcus aureus* bacteria discovered in the 1960s, called Methicillin-resistant *Staphylococcus aureus* (MRSA), has defied nearly all antibiotics. According to London's Central Public Health Laboratory, the bacteria can infect the lungs, bones and bloodstream of patients and are responsible for thousands of deaths worldwide each year. Brian Spratt, Professor of Molecular Microbiology in the Infectious Disease Epidemiology Department of Imperial College, London, said: "MRSA is clearly a very serious public health threat."

Hospital-acquired MRSA infections have increased dramatically

MRSA is most often contracted in hospital environments. The incidence of MRSA in hospitals increased by an astonishing 40% from 1994 to 1999. MRSA now accounts for 52% of all *Staphylococcus aureus* hospital-acquired infections.

Common factors associated with acquiring hospital-borne MRSA include prolonged hospital stays, the use of broad-spectrum antibiotics, duration of antibiotic usage, residence in intensive care or burn units, the presence of surgical wounds and proximity to other patients who are infected by the organism.

Hospital taps, handles and computer keyboards are reservoirs for MRSA infection. Other touch surfaces in hospitals, such as instrument handles, equipment trolleys, intravenous poles, push plates, grab bars, panic bars, trays, pans, bedrails, walkers, handrails and stair rails are other probable sources of hospital-acquired infection.

MRSA is generally spread through direct contact via the hands of healthcare workers. Once inside a hospital environment, MRSA is extremely difficult to eradicate — only 15% of reported outbreaks have been completely eliminated.

Hand-washing is insufficient to control MRSA in neonatal intensive care units

Hand-washing reduces the spread of hospital-acquired infections from Gram-negative bacteria (GNB), such as coagulase-negative *staphylococci* (CNS) and *Staphylococcus aureus*. It was found that hospital staff directly involved in patient care exhibit more antibiotic-resistant organisms than staff who are not directly involved with patient care. These findings suggest that hand-washing alone is insufficient in deterring resistant strains and underscores the importance of improving infection control practices.

Precautionary measures are needed to control MRSA in long-term care facilities

Long-term care facilities (nursing homes, chronic disease hospitals, rehabilitation centres, foster and group homes, and mental institutions) are common breeding grounds for various pathogens, including MRSA. In the United States, almost as many hospital-acquired infections occur annually in America's long-term care facilities as in hospitals. Furthermore, resistant strains tend to persist and become endemic in long-term care facilities.

Community-acquired MRSA is on the rise

Recently, MRSA has taken a new turn by spreading outside of health-related facilities, indicating that its epidemiology has changed. Community-acquired outbreaks have been reported among prison inmates, contact-sport athletes, military recruits and children in daycare centres.

Treating MRSA is difficult

MRSA cannot be treated effectively with common antibiotics. Therefore, medical practitioners must resort to unusual, expensive and potentially dangerous medicine cocktails in their attempt to cure patients.

New antibiotics are not being developed

Recently, the pharmaceutical industry has not been motivated to develop a pipeline of stronger antibiotics to meet the threat from Methicillin- and Vancomycin-resistant strains of bacteria. There is little economic incentive to develop antibiotics, because they are typically prescribed for a maximum of only ten days to two weeks and are, therefore, not as profitable as medications used daily for chronic conditions, such as heart disease, high blood pressure or high cholesterol.

What's needed now

The problem of hospital acquired infections is a complex one requiring a multidisciplinary approach from healthcare workers, facilities managers, architects and designers. There is no single solution, rather a raft of measures including improved hand hygiene, pre-admission screening of patients, isolation of infected patients, review and monitoring of antibiotic regimes and improvements to general environmental hygiene.

In practice, hygienic measures may be insufficiently implemented, so antimicrobial surfaces can play an important role in reducing environmental contamination and limiting cross-infection.

Antimicrobial touch surfaces have the potential, in conjunction with other measures, to prevent the spread of infectious disease.

Antimicrobial Efficacy Experiments on Touch Materials in Hospitals

A research team from the University of Southampton (UK) compared the survival rate of MRSA on stainless steel (the most commonly used metal in healthcare facilities) with those of copper alloys.

Their results led them to conclude that the contemporary application of stainless steel for work surfaces and furnishings in hospital environments is potentially exacerbating an already critical situation with regard to MRSA transmission and infection. The team strongly believes that using copper alloys for touch surfaces in hospitals can reduce MRSA infections.

Copper and brass doorknobs can eliminate pathogenic microbes in hospitals

To the naked eye, stainless steel hardware, silver in colour and shiny, appears to be clean. Brass hardware, on the other hand, somehow may not appear quite as clean. Yet, when it comes to the survival of microbial populations on these materials, looks are decidedly deceiving.

In a research paper on streptococcal and staphylococcal growth rates on stainless steel and brass published more than two decades ago in *Diagnostic Medicine*, P Kuhn (1983) observed heavy growth on stainless steel of Gram-positive organisms and an array of Gram-negative organisms, including *Proteus s.p.* Only sparse growth was observed on brass doorknobs. This led the author to conclude that “brass is bactericidal, and stainless steel is not.”

Bacterial broths of *E. coli*, *Staphylococcus aureus*, *Streptococcus* group D, and *Pseudomonas aeruginosa* were then inoculated on stainless steel, brass, aluminum and copper to compare antimicrobial efficacies. The results, according to Kuhn, were “striking.” Aluminum and stainless steel produced heavy growth of all microbial species within eight days.

Alarmingly, most of the microbes remained on these metals after three weeks when the investigation was terminated. Copper and brass, on the other hand, showed little or no microbial growth at all. In fact, copper began to disinfect itself immediately and measurably within fifteen minutes.

Freshly-scoured brass disinfected itself within one hour. Untreated brass samples disinfected in seven hours or less, depending upon the size of the inoculum and the condition of the surface.

Brass vs stainless steel

Dresher (2002) notes other interesting points in Kuhn’s research:

- Newly-installed brushed stainless steel doorknobs and push plates were less sanitary than the tarnished brass fixtures that had been recently removed;
- Brushed surfaces on stainless steel provide a safe haven for microbes;
- For surfaces that are not bacteriostatic, such as aluminum and stainless steel, germicides must be used on a regular basis;
- Tests from the study suggest stainless steel doorknobs and push plates would have to be sanitised as often as every 15 minutes to match the protection naturally provided by bacteriostatic copper and brass.

Because copper and brass are antimicrobial, whereas stainless steel and aluminum are not, Kuhn suggests hospitals retain their old brassware. Moreover, given the apparent contrary antimicrobial evidence regarding stainless steel and aluminum, the author further suggests that, if hospitals have stainless steel or aluminum doorknobs and push plates, these materials should be plated with brass or disinfected every day to prevent the spread of contaminants.

Kuhn's observations were confirmed two decades later by Hosokawa and Kamiya (2002), who studied stainless steel door handles at a 759-bed facility in Ube, Japan. Despite the hospital's good hygiene policies (including hand-washing by healthcare staff before and after contact with patients), stainless steel door handles on 53 out of 196 rooms (27%) were found to be contaminated by Methicillin-susceptible *Staphylococcus aureus* (MSSA) and/or MRSA.



One in five door handles (19%) exhibited live pathogens in rooms with MRSA-infected patients. This high incidence of live, toxic microorganisms on stainless steel door handle surfaces led the researchers to conclude that 'extensive' contamination of MSSA and MRSA existed at the hospital. Since the other experiments confirmed that MRSA survive for long periods of time, stainless steel door handles, if not cleaned appropriately, are conduits for long-term MRSA contamination.

Copper surfaces can eliminate MRSA; stainless steel cannot

It was not until 2004 that Noyce and Keevil from the University of Southampton definitively demonstrated that copper alloys can eliminate MRSA. The research team compared the survival rates of MRSA on stainless steel (the most commonly used metal in healthcare facilities) with those of various copper alloys. The results confirmed copper's ability to control MRSA, the 'superbug.'

The research team's findings were dramatic:

- At room temperature, MRSA were able to persist and remain viable in dried deposits on stainless steel (S30400) for periods of up to 72 hours (three days).
- Copper alloys, C19700 (99% copper) and C24000 (80% copper), killed all MRSA within 1.5 hours and 3.0 hours, respectively. C77000 (55% copper) brought about significant reductions in just 4.5 hours.
- Faster antimicrobial efficacies are associated with increased copper content of the alloys. Hence, MRSA is destroyed faster on 99% copper than on 80% copper and faster on 80% copper than on 55% copper.

"MRSA infections in hospitals are pretty rife and out of control," said Noyce in a statement to BBC News (July 5, 2004). "The main mechanism of transfer is through cross-contamination on work surfaces and contact surfaces, such as door handles and push plates. If you changed some of these surfaces to copper-based alloys, these bacteria would be dead in 90 minutes." Noyce advised hospitals to switch materials from stainless steel to copper alloys in critical-care areas where patients are at greatest risk of being infected.

Frequently Asked Questions

What is meant by 'antimicrobial'?

'Antimicrobial' is the ability to inactivate microbes, such as bacteria, fungi and viruses.

Does copper have antimicrobial properties?

Yes. It has been demonstrated clearly in many studies conducted over several decades that copper inactivates some of the most toxic species of bacteria, fungi and viruses.

Do aluminum, stainless steel and plastics have antimicrobial properties?

No. Comparative antimicrobial efficacy studies have been conducted on copper, aluminum, stainless steel, PVC and polyethylene. While it has been clearly demonstrated that copper is able to eradicate microbes quickly and effectively, there is no evidence at all that aluminum, stainless steel, PVC or polyethylene exhibit any antimicrobial properties.

Which microbial pathogens can copper kill?

The scientific literature cites the efficacy of copper to kill many different types of harmful microbes, including *Actinomucor elegans*, *Aspergillus niger*, *Bacterium linens*, *Bacillus megaterium*, *Bacillus subtilis*, *Brevibacterium erythrogenes*, *Candida utilis*, *Candida albicans*, *Penicillium chrysogenum*, *Rhizopus niveus*, *Saccharomyces mandshuricus*, *Saccharomyces cerevisiae*, *Torulopsis utilis*, *Tubercle bacillus*, *Achromobacter fischeri*, *Photobacterium phosphoreum*, *Paramecium caudatum*, *Poliovirus*, *Proteus*, *Escherichia coli*, *Staphylococcus aureus* and *Streptococcus* Group D.

In recent years, antimicrobial efficacy studies on various contact surfaces have clearly demonstrated that copper and certain copper alloys can readily eradicate several of the most potent types of microbes, including *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Campylobacter jejuni*, *Salmonella enteritidis*, *Legionella pneumophila*, Methicillin-resistant *Staphylococcus aureus* (MRSA) the antibiotic-resistant superbug, as well as *Enterobacter aerogenes*, *Pseudomonas aeruginosa*, and *Influenza A* (H1N1).

Why does copper have antimicrobial properties?

The exact mechanism for copper's antimicrobial effect are still unknown and the subject of on-going research. Several distinct mechanisms are hypothesised and believed to act simultaneously. A critical factor believed to be responsible for copper's antimicrobial properties is copper's ability to readily accept or donate electrons. This electro-chemical property enables copper to participate in chemical reactions (Fenton-like reactions) that cause oxidative damage to the cell. Further, excess copper ions bind to intracellular proteins and inhibit their function or cause protein

degradation. It has also been observed that copper is responsible for lesions in the cell wall, causing leakage of essential cellular components. These and other mechanisms are hypothesised to be why copper inactivates many types of bacteria, fungi and viruses and are the subject of ongoing studies.

Describe the antimicrobial efficacy of copper

Under specific conditions, copper can inactivate microbes or prevent their further growth. Its efficacy and rate of microbial inactivation are dependent on temperature, copper ion concentration and the type of microorganism with which it is in contact. Under optimal conditions, survival rates of 0% have been achieved for certain microbes when they have been in contact with copper.

Scientific investigations have proven the efficacy of copper and copper alloys as hygienic, antimicrobial materials capable of controlling pathogenic microbes in various environments.

How is copper currently used as an antimicrobial agent?

Copper is an active ingredient in many different types of antimicrobial products. In agriculture, copper sulphate, copper-8-quinolate, copper octoate, nanocopper oxide, alkaline copper quat and copper azole are used to fight fungi in crops, textiles and wood. In marine environments, copper-based paints and copper sheathing on boats and offshore platforms exhibit potent antifouling properties. In healthcare environments, copper incubators resist microbial growth, and copper chloride solutions have antimicrobial efficacies similar to disinfection and sterilisation chemicals used in the medical-devices industry. For consumers, copper is an active ingredient in antiplaque mouthwashes, toothpastes and medicines. Copper sink strainers and scourers for pots and pans can help prevent cross-contamination in the kitchen.

Can copper metal and alloy surfaces inactivate microbes?

Yes. Extensive experimental studies conducted over the past few years have confirmed that copper and certain copper alloys inactivate pathogenic microbes on contact, both at room and chill temperatures.

For example, the Keevil (2000) study and others show that at 20°C (room temperature) *E. coli* O157 perish completely on copper in just 4 hours. On stainless steel, these toxic bacteria remained viable for 34 days. At 4°C (chill temperature), *E. coli* O157 are completely inactivated on copper in just 14 hours. On stainless steel, however, the bacteria continue to be viable for several months.

The antimicrobial efficacy and rate of inactivation of microbes by contact with copper alloys generally increases with the copper content of the alloy. For example, at room temperature, MRSA are completely eliminated within 1½ hours on a 99% copper alloy and within 3 hours on an 80% copper alloy. They are significantly reduced within 4½ hours on a 55% copper alloy. On stainless steel, however, MRSA are able to persist and remain viable in dried deposits for up to 72 hours (three days).

Survival rates of *Listeria monocytogenes* on copper, brass and high-silicon bronze are limited to 60 minutes at room temperatures. Alloys of lower copper content, such as copper-nickel and nickel silver, are able to eliminate *Listeria monocytogenes* in 70–85 minutes. On stainless steel, *Listeria monocytogenes* can survive for several days.

Salmonella enterica and *Campylobacter jejuni* populations are also inactivated when in contact with copper. Populations of both these microbes are reduced by 99% within 4 hours of contact at 25°C.

This research holds promise also for the potential role of copper in helping to reduce the incidence of infection from airborne pathogens in HVAC systems, as well as the incidence of cross-contamination from dangerous foodborne, hospital-borne and community-borne pathogens.

Describe opportunities for inactivating airborne pathogens in HVAC environments with copper

In today's modern buildings, there is strong concern about indoor air quality and exposure to toxic microorganisms. This has created a dire need to improve hygienic conditions of HVAC systems, which are believed to be factors in over 60% of all sick-building situations (for example, aluminium fins in HVAC systems have been identified as sources of significant microbial populations). In immunocompromised individuals, exposure to potent microorganisms from HVAC systems can result in severe and sometimes fatal infections. The use of antimicrobial copper instead of biologically-inert materials in heat exchanger tube, fins, condensate drip pans and filters is a viable and cost-effective means to help control the growth of bacteria and fungi that thrive in dark, damp HVAC systems.

Describe opportunities for inactivating foodborne pathogens with copper

Hygiene regulations and industry self-monitoring are insufficient to protect the quality of the world's food supplies. Hygienic contact surfaces, such as copper and copper alloys, can help to reduce the incidence of cross-contamination of dangerous foodborne pathogens, such as *E. coli* O157, *Campylobacter*, *Listeria monocytogenes* and *Salmonella* at food-processing operations. Copper has an intrinsic ability to quickly inactivate these dangerous microbes at both refrigerated temperature (4°C) and at room temperature (20°C).

Describe opportunities for using copper to inactivate hospital-borne pathogens

Despite enormous advances in understanding how pathogenic microbes cause illnesses and death, inadequate hygienic practices at health-related facilities have contributed towards a dramatic number of hospital-borne infections — some 300,000 each year in the UK, alone. Copper has an intrinsic ability to kill *E. coli* O157, *Legionella pneumophila*, *Staphylococcus aureus*, *Streptococcus*

Group D, *Enterobacter aerogenes* and *Pseudomonas aeruginosa*, as well as MRSA (the deadly pathogen that has become a primary concern of healthcare administrators around the world). This strongly suggests that the replacement of touch surfaces with copper alloys at healthcare facilities can help to reduce the incidence of microbial infection due to contaminated surfaces.

Examples of products that would benefit from hygienic copper alloy touch surfaces include door handles, push plates, bedrails, bed trays, remote controls, grab rails, taps, towel bars, dispensers (soap, paper towel, alcohol gel, apron), chairs, instrument handles, equipment trolleys, intravenous poles and exercise and rehabilitation equipment.

Will copper surfaces change colour or tarnish?

Yes. Copper and copper alloy surfaces naturally develop a tarnish film and change colour over time. The amount of time needed for a colour change to occur depends on the alloy and exposure conditions. In typical indoor exposure, appreciable colour changes can take many years to develop.

Does tarnishing deter copper's antimicrobial effect?

No. Tarnishing does not deter copper's antimicrobial effect. In fact, studies show that the antimicrobial efficacy of copper and its alloys is enhanced with the development of a tarnish layer.

Definitions of Copper's Antimicrobial Action

The following definitions are applied in this publication when describing copper's effect on microorganisms. (The definitions are adapted from Black, J G (1966) Microbiology: Principles and Applications. Third Edition. Prentice Hall, pp 332-352.)

Bacteriostatic/fungistatic: A '-static' agent inhibits microbial growth by means other than killing; a '-static' agent limits the growth of microorganisms and may inactivate them.

Antimicrobial: An 'antimicrobial' substance (chemical or physical) can prevent microbial growth either by some '-static' action or by the outright killing of microbes.

Bactericidal/fungicidal: A '-cidal' agent either damages a microorganism at low concentration and/or reduced contact time or interacts permanently with it so that it ceases to function normally. Such an agent damages a microorganism sub-lethally; total inactivation is functionally equivalent to killing the organism (0% survival).

Sanitisation: Sanitisation is the cleaning of pathogenic microorganisms from public objects or surfaces, leading to improved hygiene.

Hygienic surface: A hygienic surface inhibits microbial growth and may totally inactivate certain organisms.

Disinfection: Disinfection is the process of reducing the number of pathogenic organisms on objects or in materials so that they pose no threat of disease.

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