Using Copper Oxide in Medical Devices and Textiles to Fight Disease – Effective, Inexpensive and Feasible

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Abstract

Copper ions, either alone or in copper complexes, have been used for centuries to disinfect liquids, solids and human tissue. Today copper is used as a water purifier, algaecide, fungicide, nematocide, molluscicide, and anti-bacterial and anti-fouling agent. Copper also displays potent anti-viral activity. Introducing copper into cotton fibers, latex and other polymeric materials enables the production of clothing, bedding and medical devices that possess biocidal properties [1]. Some examples include anti-viral gloves and filters (which deactivate HIV-1 and other viruses), anti-bacterial self-sterilizing fabrics (which kill antibiotic resistant bacteria), anti-fungal socks (which alleviate symptoms of athlete's foot), and anti-dust mite mattress-covers (which reduce mite-related allergies). This paper will discuss the potential applications of this novel technology especially in the context of fighting diseases in developing countries. These applications include medical issues of the greatest importance, such as viral transmissions and nosocomial infections.

Introduction

Metal ions have been used for centuries to disinfect fluids, solids and tissues [2]. The ancient Greeks (400 BC) prescribed copper for pulmonary diseases and for purifying drinking water. The Celts produced whisky in copper vessels in Scotland around 800 AD, a practice that has continued to the present day. Copper strips were nailed to ship's hulls by the early Phoenicians to inhibit fouling, as cleaner vessels were faster and more maneuverable. Gangajal (holy water taken from the Ganges River) has been stored in copper utensils in Hindu households for centuries due to copper's anti-fouling and bacteriostatic properties. By the 18th century, copper had come into wide clinical use in the western world for the treatment of mental disorders and afflictions of the lungs. Early American pioneers moving west across the continent put silver and copper coins in large wooden water casks to provide them with safe drinking water for their long voyage. In World War II, Japanese soldiers put pieces of copper in their water bottles to help prevent dysentery. Copper sulphate is highly prized by some inhabitants of Africa and Asia for healing sores and skin diseases. NASA first designed an ionization copper-silver sterilizing system for its Apollo flights.

Today copper is used as a water purifier, algaecide, fungicide, nematocide, molluscicide, and as an anti-bacterial and anti-fouling agent [3-7]. It is considered safe to humans, as demonstrated by the widespread and prolonged use of copper intrauterine devices (IUDs) by women [8,9]. In contrast to the low sensitivity of human tissue (skin or other) to copper [10], microorganisms are extremely susceptible to copper. For example, it has recently been shown that copper surfaces reduce survival of epidemic meticillin-resistant *Staphylococcus aureus* in the healthcare environment [11]. Copper toxicity to microorganisms, including viruses, may occur through the displacement of essential metals from their native binding sites, from interference with oxidative phosphorylation and osmotic balance, and from alterations in the conformational structure of nucleic acids, membranes and proteins [12].

Impregnation of copper oxide into polymeric fibers

Utilizing the properties of copper, a durable platform technology has been developed in which polyester, polypropylene, polyethylene, polyurethane, polyolefin, or nylon fibers are impregnated with copper oxide [1;13]. Basically, impregnation of copper into the various synthetic fibers mentioned above is achieved by adding a cupric oxide powder to the polymers during the master batch preparation stage. The master batch can be made in industrially accepted concentrations and added to the polymeric slurry in the same manner as any other master batch would be added, such as for pigmentation, etc. The copper oxide doped master batch is designed in such a way as to allow fiber extrusion in the normal production systems. The fibers can be cut into short staple or produced in filament form and texturized, if so desired. The impregnated fibers can be introduced at the blending stage of yarn production or directly into nonwoven products so that no manufacturing processes are changed. Thus, the mass production of woven or non-woven fabrics into which copper oxide treated fibers have been introduced is easily achieved without any alteration of industrial procedures or machinery. As an example, this technology was utilized to produce nonwoven fabrics containing up to 8% copper oxide additive (Figure 1).

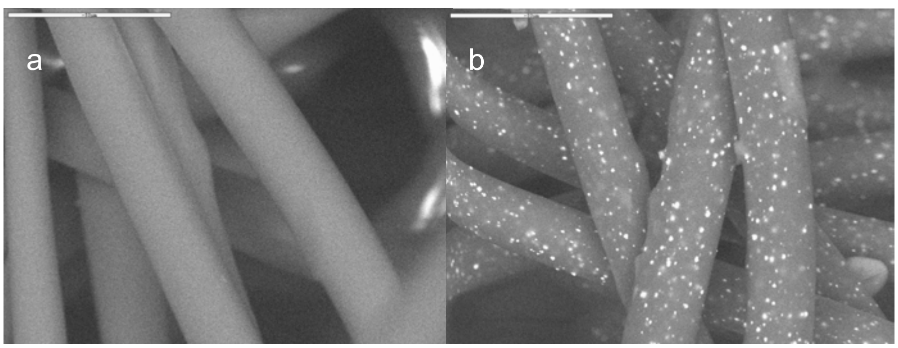

Figure 1. Scanning electronic microscope (SEM) images of nonwoven fabrics containing 0% (a) or 3% (b) copper oxide (w/w) particles embedded in the polypropylene fibers.

Importantly, these copper oxide impregnated nonwoven fabrics possess broad-spectrum biocidal properties: they are anti-bacterial, anti-fungal, and anti-viral (Figure 2).

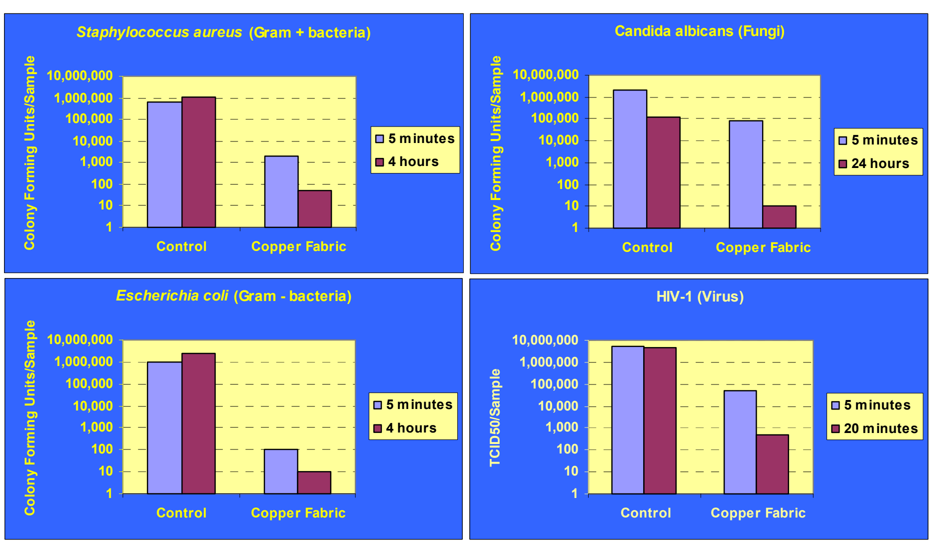

Figure 2. Biocidal properties of copper oxide impregnated nonwoven fabrics. The American Association of Textile Chemists and Colorists (AATCC) Test Method 100-1993 was used to determine the biocidal properties of the fabrics against the bacteria and fungi tested. These tests were carried out by an independent laboratory: AminoLab Laboratory Services, Weizmann Industrial Park, Nes Ziona 79400, Israel. The HIV-1 testing was done in-house. For further experimental details, please see Reference [1].

Exposure of bacteria, fungi or viruses to fabrics containing 3% (w/w) copper oxide particles for a period as short as five minutes resulted in more than 2 log reduction (>99%) in their titers. Prolongation of the exposure of these microorganisms to the fabrics (20 minutes for HIV-1, 4 hours for the bacteria and 24 hours for the fungi) further reduced their viable titers by more than 4 logs (>99.99%). Similar results were obtained for other fabrics [13].

Discussion

By utilizing the properties of copper, an inexpensive platform technology was developed which permanently binds copper to textile fibers from which woven or nonwoven fabrics can be produced. Animal studies demonstrated that the copper treated fabrics do not possess skin sensitizing properties [1,13]. Furthermore, none of the 100 individuals who used socks containing copper impregnated fibers to alleviate their athlete's foot conditions reported any negative effects caused by the socks (Ref [13] and manuscript submitted). Similarly, none of the 100 patients, who slept on sheets containing copper treated fibers, reported any adverse effects [13]. These findings are in accordance with the very low risk of adverse skin reactions associated with copper [10].

The possibility of introducing copper oxide into fabrics may have significant ramifications. One example is the reduction of nosocomial infections in hospitals. Over 90,000 deaths in the US are attributed to these infections each year and one out of four deaths in intensive care units is caused by an infection unrelated to the initial cause of hospitalization. In developing countries the problem may be even more dramatic as the standard of care is generally lower and the rate of infection in the community is generally higher. The main sources for contamination are the patient's skin flora, the flora on the hands of medical and nursing staff, and contaminated infusion fluids. However, it has recently been demonstrated that sheets which are in direct contact with a patient's skin and his bacterial flora are an important source of infection [14-16]. Moreover, sheets were significantly more contaminated by patients carrying infection than by non-infected patients ($p<0.01$) [16]. Therefore, use of fabrics that kill microbes in pajamas, sheets, pillow covers, and robes in a hospital setting, may reduce the spread of microorganisms in hospital wards, resulting in a reduction of nosocomial infections. Although the contribution of airborne transmission of pathogens to nosocomial infections has been controversial, much data is accumulating to support the notion that airborne transmission of bacteria significantly contributes to hospital acquired infections (reviewed in Ref [16]). Airborne transmission is known to be the route of infection for diseases such as tuberculosis and aspergillosis. It has also been implicated in nosocomial outbreaks of MRSA [17-19], *Acinetobacter baumannii* [19] and *Pseudomonas aeruginosa* [20]. Furthermore, hospital ventilation systems have also been implicated with nosocomial MRSA outbreaks [16,17]. Preliminary data indicate that addition of copper oxide impregnated nonwoven fabrics into air filters significantly reduces the passage of viable microbes (unpublished results). Thus, the use of nonwoven copper impregnated fabrics in air filters in a hospital setting may reduce the spread of microorganisms in hospital wards, resulting in a reduction of nosocomial infections.

Similarly, the use of copper impregnated nonwoven fabrics in disposable hospital textiles, such as in barrier fabrics, will not only confer protection on the wearer from possible pathogens to which he/she may be exposed, for example in contaminated blood, but will also confer protection to the immediate environment from these pathogens, reducing transmission of pathogens in hospitals.

Another important potential application of copper impregnated fibers is related to the reduction of bacterial and viral transmission during transfusion of blood or blood related products. The safety of whole blood and its components is a continuing global problem [21]. A growing number of viral, bacterial, and protozoa pathogens have been identified in blood products, and new pathogens are regularly identified as present. While the current estimate of HIV transmission through blood transfusions in the US is approximately 1 in 2,000,000 units [22], new viruses are constantly being discovered in the blood supply. Inexpensive rapid screening tests for emerging viruses generally take time to develop. One need only remember the recent panic relating to West Nile virus in the blood supply where it has been estimated that 1 in 5,000 [23] units were infected before the problem was even detected**.** Recent findings reveal that while quarantine-stored fresh frozen plasma contains physiologically active, therapeutically relevant, plasma proteins, it also carries a risk of transmitting HIV and other viruses. Mortality and morbidity associated with blood transfusions that are contaminated by pathogens have been well established. In response, regulatory agencies and blood bank standards groups have called for efficient new technologies to improve the safety of blood products. In areas of the world where screening tests are too expensive to be performed regularly, a cheap, rapid virus inactivation filter would be extremely helpful. Even in the US, hospitals can no longer afford to pay for expensive tests for each 'pathogen du jour' [24]. Accordingly, a filter that can inactivate a broad spectrum of viruses in blood products would be very valuable. Preliminary unpublished results showing the neutralization of HIV-1 infectivity when viruses were passed through syringes containing copper oxide impregnated nonwoven fabrics indicate the possibility of producing a generic anti-viral filter. However, it must first be established that these filters do not damage filtered plasma and other blood components and that they do not harm individuals infused with these blood products. These studies are currently in progress.

A further possible use of filters containing copper impregnated nonwoven fabrics is related to the reduction of HIV-1 transmission through breast-feeding. Transmission of HIV during lactation accounts for one third to one half of all HIV mother-infant transmissions [25]. This is a tenacious global problem lacking straightforward solutions [26]. In sub-Saharan Africa, the problem has been deemed a "disaster," while the growing incidence of breastfeeding-acquired pediatric HIV infection in other developing countries, such as India and China, amplify the looming threat worldwide. In 2001, breastfeeding was estimated to have contributed 33 - 50% of the over 700,000 maternal-to-child HIV transmissions worldwide. Paradoxically breastfeeding promises the best chance of adequate nutrition and immunological protection for infants born in developing nations, with *not breastfeeding* estimated to engender 1.5 million child deaths per year from malnutrition and infection [25-32]. Thus, when replacement feeding is not an affordable, culturally-acceptable, safe, or sustainable option, exclusive breastfeeding of infants to 6 months by HIV-infected mothers, followed by rapid weaning to replacement feeding is recommended by the major global health organizations (WHO, UNICEF, CDC). Breast milk may thus be passed through a copper fiber-containing filter reducing HIV infectivity. If there is no degradation to the milk's essential nutrients as a result of filtration, the filtered milk may be fed to infants thereby reducing the risk of HIV transmission. Admittedly, implementing such measures may be very difficult because of sociological factors existing in developing countries. However, HIV-1, as well as other viruses, will be with us for many years and methods to reduce their impact must be developed. In addition, a disposable one-time use nipple shield containing copper oxide is under development, which may be more acceptable and feasible in developing countries where HIV-1 infection is rampant.

In conclusion, this study demonstrates the potential uses of copper in new applications that address medical concerns of the greatest importance. Implementation of even a few of the possible applications of this technology may have a major effect on the lives of many.

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