Ultrasonics Sonochemistry 25 (2015) 82–88

Contents lists available at ScienceDirect

Ultrasonics Sonochemistry

journal homepage: www.elsevier.com/locate/ultson

Making the hospital a safer place by sonochemical coating of all its textiles with antibacterial nanoparticles

Ilana Perelshtein [a], Anat Lipovsky [a], Nina Perkas [a], Tzanko Tzanov [c], M. Arguirova [d], M. Leseva [e], Aharon Gedanken [a,b,]*

[a] Department of Chemistry and Kanbar Laboratory for Nanomaterials, Bar-Ilan University Center for Advanced Materials and Nanotechnology, Ramat-Gan, Israel
[b] The Department of Materials Science & Engineering, National Cheng Kung University, Tainan 70101, Taiwan
[c] Universitat Politècnica de Catalunya, Edifici Gaia, Pg. Ernest Lluch/Rambla Sant Nebridi s/n, 08222 Terrassa, Spain
[d] Burn and Plastic Surgery Clinic, MHATEM, N.I. Pirogov, Sofia, Bulgaria
[e] Clinical Microbiological Laboratory, MHATEM, N.I. Pirogov, Sofia, Bulgaria

ARTICLE INFO

Article history:
Received 27 July 2014
Received in revised form 2 October 2014
Accepted 21 December 2014
Available online 5 January 2015

Keywords:
Sonochemistry
Scale-up
Coating ZnO
CuO
Antibacterial textiles

ABSTRACT

The ability to scale-up the sonochemical coating of medical textiles with antibacterial nanoparticles is demonstrated in the current paper. A roll-to-roll pilot installation to coat textiles was built taking into consideration the requirements of the sonochemical process. A long-run experiment was conducted in which 2500 m of fabric were coated with antibacterial ZnO nanoparticles (NPs). The metal oxide NPs were deposited from an ethanol:water solution. In this continuous process a uniform concentration of coated NPs over the length/width of the fabric was achieved. The antibacterial efficiency of the sonochemically-coated textiles was validated in a hospital environment by a reduction in the occurrence of nosocomial infections. NP-coated bed sheets, patient gowns, pillow cover, and bed covers were used by 21 patients. For comparison 16 patients used regular textiles. The clinical data indicated the reduced occurrence of hospital-acquired infections when using the metal oxide NP-coated textiles.

In order to reduce the cost of the coating process and considering safety issues during manufacturing, the solvent (ethanol:water) (9:1 v:v) used for the long-run experiment, was replaced by water. Although lesser amounts of ZnO NPs were deposited on the fabric in the water-based process the antibacterial activity of the textiles was preserved due to the smaller size of the particles.

1. Introduction

Hospital-acquired nosocomial infections are a major health and financial issue worldwide. The problem of bacterial infections in general, and in hospitals in particular, has led to extensive research and to industrial efforts to produce antibacterial textiles. The financial impact of these infections overwhelms the current medical advances by increasing the length of hospitalization by at least 8 days on the average per affected patient, resulting in more than 10 million patient days in hospitals in Europe per year [1]. The statistics on patient safety in the EU show alarming tendencies: 1 in 10 patients are affected by hospital-acquired infections, 3 million deaths are caused yearly by hospital-acquired infections.

In the last 2 decades, due to the continuous consumption of antibiotics, and the evolution and spread of resistance genetic determinants, multidrug resistant (MDR) and even extremely drug resistant (XDR) bacteria that cause life-threatening infections have emerged [2]. An active infection control program could significantly reduce both the number of infections and hospitalization costs.

The most common sources of infectious agents causing healthcare problems are: the individual patient, medical equipment, the hospital environment, and the healthcare personnel. Although the person-to-person transmission route is the most likely, the role of the environment should not be ignored and hospital textiles may contribute to the spread of nosocomial infections. Since textiles are a common material in healthcare facilities, it is important that they do not transfer pathogens to patients or hospital workers. Healthcare textiles include bed sheets, blankets, towels, personal clothing, patient apparel, uniforms, gowns, and drapes for surgical procedures [3,4]. Medical textiles are often contaminated by

* Corresponding author at: Department of Chemistry and Kanbar Laboratory for Nanomaterials, Bar-Ilan University Center for Advanced Materials and Nanotechnology, Ramat-Gan, Israel.

E-mail addresses: Ilana.Perelshtein@biu.ac.il (I. Perelshtein), ecoli2310@yahoo.com (A. Lipovsky), perkasn@mail.biu.ac.il (N. Perkas), tzanko.tzanov@upc.edu (T. Tzanov), maya_arguirova@yahoo.com (M. Arguirova), mlesseva@yahoo.co.uk (M. Leseva), gedanken@mail.biu.ac.il (A. Gedanken).

http://dx.doi.org/10.1016/j.ultsonch.2014.12.012
1350-4177/

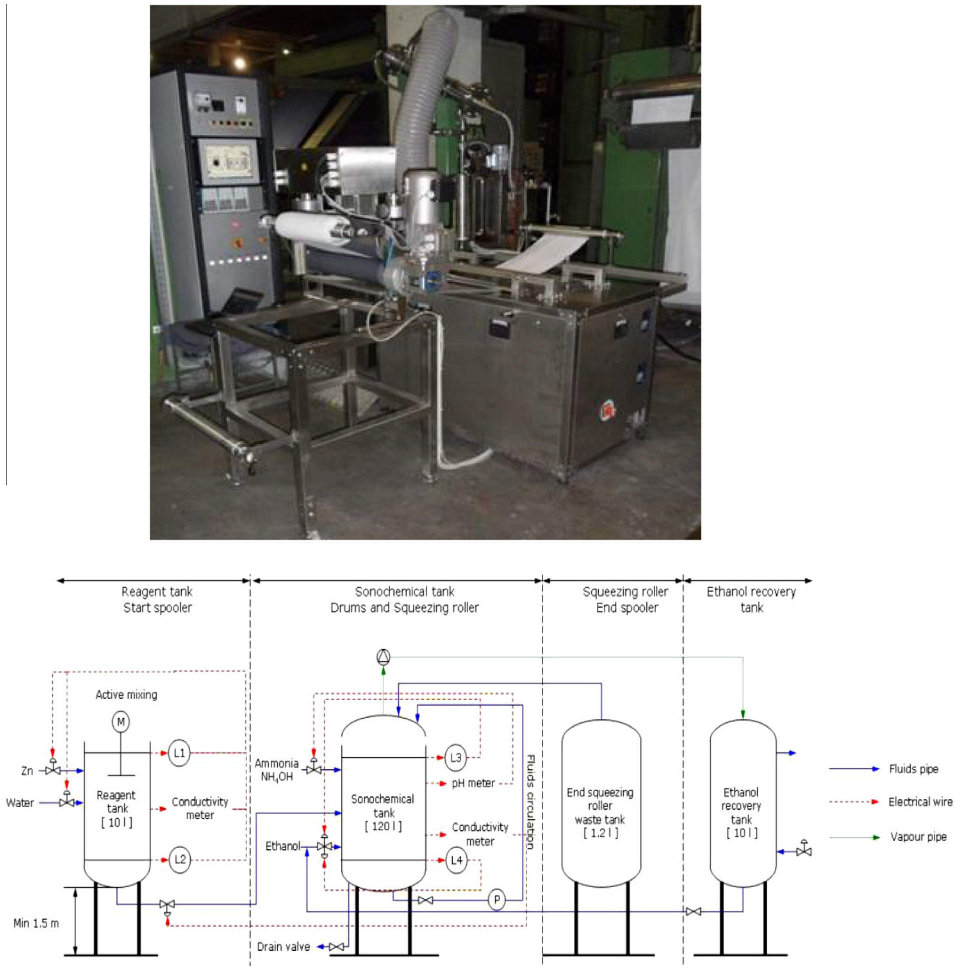

Fig. 1. Scheme of roll-to-roll pilot installation for sonochemical coating.

microorganisms originating from body substances, including blood, skin, stool, urine, vomits, and other body fluids and tissues.

The growing need for antibacterial textiles has resulted in revolutionary progress in the textile industry [5]. In the last decade, the design of new methods of fabric finishing has included the use of metal and metal oxide nanoparticles that have a high surface area and can be finely spread on the surface of the substrates [6–8]. The metal oxides can be deposited as a separate phase or in a combination of composite nanostructured materials. Most of the methods for antibacterial finishing of textiles are based on multistage procedures and require toxic templating and binding agents for the anchoring of the nanoparticles on the substrate. As a result of earlier attempts to sonochemically coat small pieces of cotton, polyester, nylon, and wool with antibacterial nanoparticles (NPs) [9,10] successfully kill of bacteria, a small machine operating in continuous mode for sonochemical coating of textile was built [11]. The machine was later upgraded to two industrial scale coating machines for continuous deposition of NPs on 40 cm wide fabrics at a speed of 1–3 m/min. ZnO and CuO NPs were coated on cotton and polyester fabric using these machines. Excellent antibacterial properties of the coated fabrics were maintained after 65 washing cycles in hospital washing regimes (75 and 92 °C) [12]. We have also demonstrated the ability of the metal oxide NPs to eradicate resistant bacteria [13].

The present manuscript reports on the improvement of the original sonochemical process for the synthesis and simultaneous deposition of metal oxide NPs on fabrics, making the synthetic route safer and more cost efficiently using water instead of an ethanol:water solution. Previously, the metal oxide NPs were prepared by the basic hydrolysis of the corresponding metal acetates in 9:1 ethanol:water (v:v). The introduction of ignitable ethanol in an industrial plant not only requires special protective equipment, but is also more costly than using water as the only solvent. When water replaced the ethanol:water mixture, the amount of oxides on the textile was smaller, however, the particle size was also reduced and as a result the antibacterial activity was not hampered.

This article also presents clinical results obtained in an experiment conducted in a hospital (Institute for Emergency Medicine "N.I. Pirogov" (IEM), Sofia, Bulgaria) where patients were dressed, and slept on antibacterial (ZnO) coated fabrics and their propensity to bacterial infection was monitored and compared to control patient using uncoated textiles. Since the mechanism of the sonochemical coating has been explained previously [14,15], it is not discussed in the current paper.

2. Experimental

2.1. Characterization

The batch experiments were carried out using a Sonics and Materials instrument (Ti-horn, booster, 20 kHz, 750 W at 30% efficiency). The roll-to-roll coating was carried out using a sonochemical coating pilot installation constructed by CEDRAT Technologies, Grenoble, France.

The X-ray diffraction (XRD) patterns of the product were determined using a Bruker D8 diffractometer with Cu Kα radiation. The