Development of antibacterial packaging films via sonication based on polyethylene/ZnO nanoparticles

Nazanin Sarrafzadeh[1], GholamHossein Zohuri[1*], Haniyeh MiranMousavi[2,3]
[1] *Department of Chemistry, Faculty of Science, Ferdowsi University of Mashhad, Mashhad, Iran*
[2] *Chemical Engineering Department, Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.*
[3] *Mobtakeran Novin Pezeshki Sepehr Co (of Part lastic Industrial Group), Mashhad, Iran.*
[*] *Corresponding Author's E-mail address: zohuri@um.ac.ir*

Abstract
ZnO-nanoparticles have been used widely to achieve antimicrobial films in various applications including the food industry and packaging. ZnO (0.25 w%, 0.5 w%, 0.75 w%, 1 w%, 1.5 w%, 2 w%, 3 w%, 5 w%) was loaded into LDPE along with tween 80, a surfactant, and sonication to produce antibacterial film against Staphylococcus aureus as a Gram-positive test strain and Escherichia coli as a Gram-negative test strain. The incorporation of ZnO-nanoparticles into LDPE films via sonication can enhance the antimicrobial properties of the material, providing a safer and more effective way to preserve food.
Keywords: antibacterial, packaging, LDPE, ZnO-nanoparticles, sonication.

Introduction
The development of antibacterial packaging films based on polyethylene (PE) and ZnO-nanoparticles has gained significant attention in recent years due to its potential to improve food safety and extend its shelf life. Polyethylene, particularly low-density polyethylene (LDPE), is widely used in food packaging due to its low cost, excellent mechanical resistance, and high clarity. The growth of microorganisms on the surface of these films, however, can lead to spoilage and food deterioration. To address this issue, researchers have focused on modifying PE with ZnO-nanoparticles, which has large specific surface area, stable crystal structure, high UV absorption, and strong antibacterial activity. The use of ZnO-nanoparticles in food packaging has been approved by the U.S. Food and Drug Administration (FDA) for its safety [1]. Studies have shown that the incorporation of ZnO-nanoparticles into PE films can significantly reduce bacterial growth and extend the shelf life of packaged foods. For example, a study found that LDPE films coated with ZnO-nanoparticles exhibited strong antimicrobial activity against E. coli and S. aureus, with a bacterial reduction of up to 99.99% [2]. Another study demonstrated that the addition of ZnO-nanoparticles to HDPE films resulted in a strong antimicrobial effect against E. coli, with a microbial reduction of up to 97.7%%, in addition sonication is one of the factors that has a significant effect on antibacterial properties due to the suitable dispersion of nanoparticles. These mechanisms can effectively inhibit the growth of microorganisms on the surface of the film, reducing the risk of food spoilage and contamination [3]. This study focuses on the development of antibacterial films based on low density polyethylene (LDPE) and ZnO-nanoparticles which showed great antibacterial performance to both E.coli and S. aureus.

Experimental

Materials
LDPE was kindely provided by Baspar Payesh Pars Co., Iran. Xylene and Tween 80 was purchased from Mojallali Lab., Iran. ZnO-nanoparticles (18 nm particle size and high purity 99.95%) was supplied from US Research Nanomaterials, Inc. (Houston, TX).

Preparation of films
To prepare the LDPE films containing ZnO-nanoparticles, LDPE (12 w%) was added to mixed-xylene (85≥ °C) and stirred (3 h). After stirring the solution was homogeneous and transparent. ZnO-nanoparticles (0.25 w%, 0.5 w%, 0.75 w%) were added to the solution and stirred (further 2 h). The obtained solution was casted on a hot mirror.
To prepare the LDPE films containing ZnO-nanoparticles and tween 80, ZnO-nanoparticles (0.25 w%, 0.5 w%, 0.75 w%, 1 w%, 1.5 w%, 2 w%, 3 w%, 5 w%) and Tween 80 (4 w%) were added to the same solution as described above followed by sonication (1-3 mins) (PROFESSIONAL DIGITAL ULTRASONIC CLEANER, MEDICAL, PARTS AND DENTAL CLINICS CD-4800 TANK SIZE 6.75" X 5.38" X 2.75 "(L X W X H), China) and stirring (2 h). The obtained solution was casted on a hot mirror.

The antibacterial activity

Evaluation of antimicrobial properties was carried out in accordance with the National Standard ASTM-E2180-2018. E. coli, a Gram-negative bacterium, and S. aureus, a Gram-positive bacterium, were chosen for assessment using the plate counting method.

Results and discussion

The effectiveness of tween 80 and ZnO-nanoparticles (1 w%, 3 w% and 5 w%) film samples against on both of the S. aureus and E. coli is illustrated in Figure 1, respectively. The antibacterial activity of the pure LDPE film is shown in Figure 2. The films incorporating ZnO-nanoparticles and tween 80 exhibited 100% antibacterial properties against both of E. coli and S. aureus. The antibacterial mechanism of ZnO-nanoparticles can be attributed to: (i) the sustained release of Zn^{2+} from the films, which disrupts bacterial cell membranes and disturbs their internal balance, and (ii) the ability of ZnO-nanoparticles to generate hydroxyl free radicals and reactive oxygen species in the presence of light, inducing oxidative stress that impairs bacterial reproduction and leads to bacterial demise [1,4].

On the other hand the films that didn't contain tween 80 and were not sonicated showed no antibacterial properties based on calculations. The antibacterial activity of LDPE/ZnO-nanoparticles film (0.75 w%) against E. coli and S. aureus is shown Figure 2 and the colony count table is illustrated in Table 1.

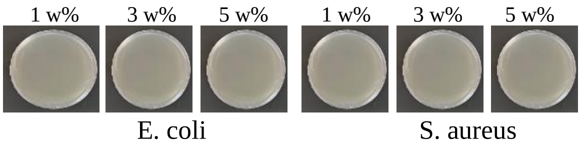

Figure. 1. The antibacterial effect of LDPE/ZnO-nanoparticles (1 w%, 3 w%, 5 w%)/Tween 80 film against E. coli and S. aureus.

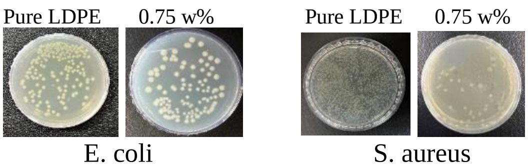

Figure. 2. The antibacterial activity of pure LDPE film and LDPE/ZnO-nanoparticles film (0.75 w%) against E. coli and S. aureus.

If the difference between the logarithms of pure LDPE $^{CFU}/_{mL}$ and treated sample is between 1 and 3, it can be inferred that one of the substances has antibacterial properties. This is a common method used to evaluate the antibacterial activity of substances, where a larger difference in logarithms indicates stronger antibacterial activity [5].

Table. 1. Logarithm of colonies for pure LDPE and (0.75 w%) LDPE/ZnO-nanoparticles.

$\log {}^{CFU}/_{mL}$	Pure LDPE	0.75 wt% LDPE/ZnO-nanoparticles
E. coli	6.37	6.03
S. aureus	5.72	5.63

Conclusions

Antibacterial LDPE films were created using the solution-castin g technique. Since films produced without sonication don't have antibacterial properties, so sonication is an integral part of the films production process. While the inclusion of ZnO-nanoparticles and tween 80 in LDPE films resulted in excellent antibacterial properties at all used ratio, only 1 w% nanoparticle is suitable to get antibacterial behaviour.

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