cbecimat26
26° Congresso Brasileiro de Engenharia e Ciência dos Materiais
22 a 26 de novembro de 2026
Costão do Santinho
Florianópolis-SC

Incorporation of EU/MMT–ZnO Nanocomposites into Linear Low-Density Polyethylene (LLDPE) for Antibacterial Film Applications.

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Introduction

In this work, an innovative antimicrobial nanocomposite designated as EU-MMT/NPZnO (Erucamide–Montmorillonite/Zinc Oxide Nanoparticles) was synthesized, characterized, and incorporated into linear lowdensity polyethylene (LLDPE) films at different concentrations. Each component of the nanocomposite was selected to perform a specific function: montmorillonite (MMT) was employed to enhance the dispersion of ZnO nanoparticles within the LLDPE matrix, while erucamide (EU) served to facilitate the migration of the active agent to the polymer surface, thereby increasing the effective antibacterial area and reducing the formation of active agent agglomerates.

Objectives

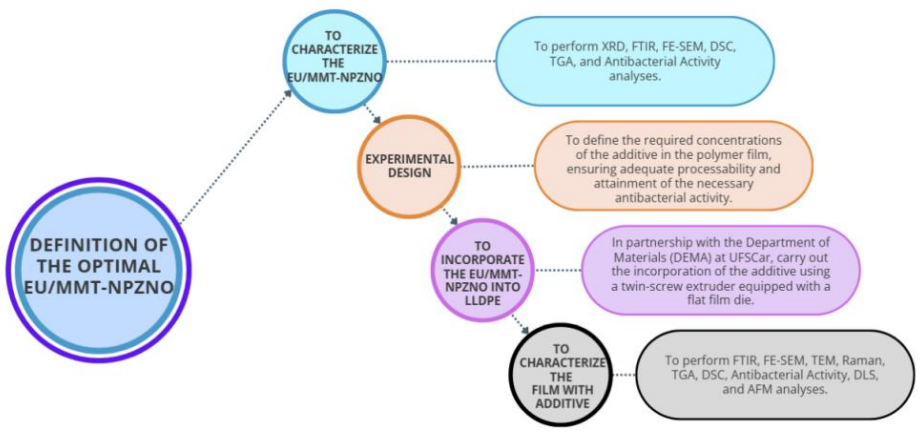


Figure 1. Schematic illustrating the objective of the study and the steps followed.

Methodology

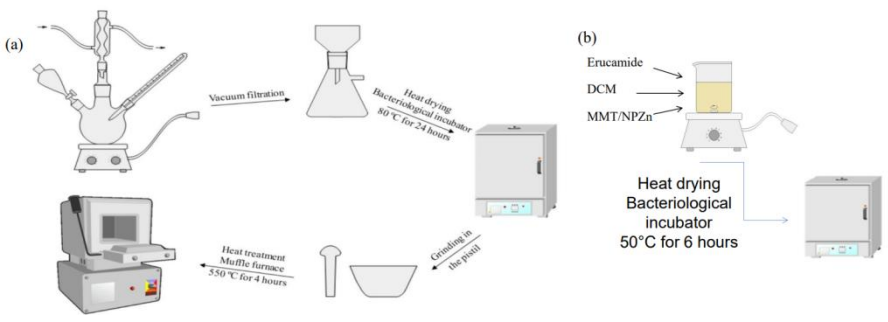


Figure 2. Methodology for obtaining the nanocomposite, from the incorporation of zinc into montmorillonite to the incorporation of erucamide into the system

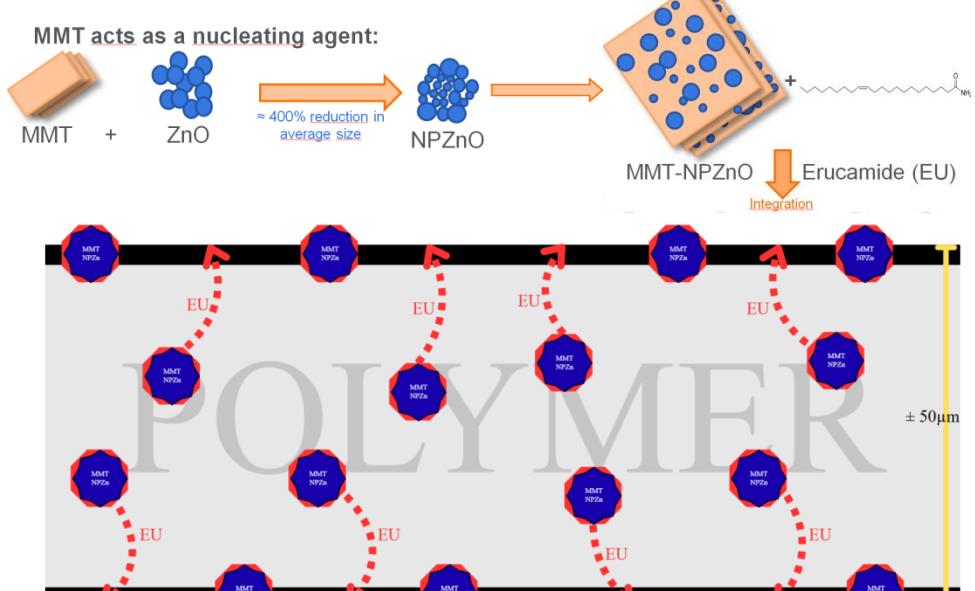


Figure 3. Merely illustrative graphical representation of the migration process of Erucamide (EU) displacing Montmorillonite particles with Zinc Nanoparticles (MMTNPZn) to the surface of the polymer film.

Results & Discussion

	LLDPE (g)	Additive (g)	Total mass (g)	Batches
LLDPE + NPZn (10%)	135,0	15,0	150,0	1
LLDPE + EU (3%)	145,5	4,5	150,0	1
LLDPE + EU/MMT-NPZn (10%)	135,0	15,0	150,0	4

Table 1. Planning of masterbatch preparation for incorporation in the extrusion process.

	LLDPE (g)	Masterbatch (g)	EU/MMT-NPZn (g)	EU (g) Corresponding	NPZn (g) Corresponding
Pure LLDPE	1000,00	0,00	0,00	0,00	0,00
LLDPE + NPZn 10000ppm	900,00	100,00	0,00	0,00	10,00
LLDPE + EU 3000ppm	900,00	100,00	0,00	3,00	0,00
LLDPE + EU/MMT-NPZn 1000ppm	923,10	76,90	7,96	1,00	3,34
LLDPE + EU/MMT-NPZn 2000ppm	846,20	153,80	15,38	2,00	6,64
LLDPE + EU/MMT-NPZn 3000ppm	769,30	230,70	23,07	3,00	10,02

Table 2. Extrusion planning of the materials to be studied.

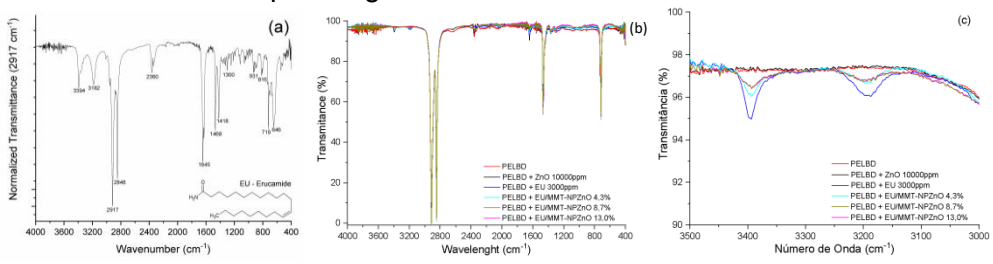


Figure 4. FTIR-ATR spectra of (a) pure erucamide, (b) all produced films in the range of 400–4000 cm^{-1}, and (c) a detailed view of the 3000–3500 cm^{-1} region.

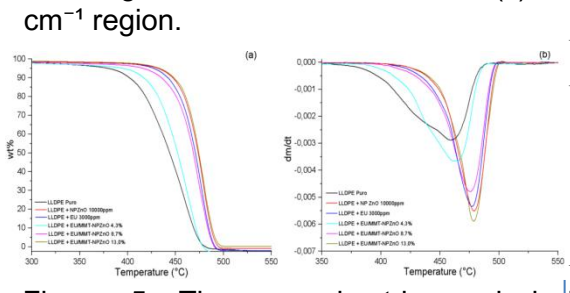


Figure 5. Thermogravimetric analysis (TGA) of all films (a) and their derivative thermogravimetric (DTG)(b).

ID	T_{onset} 5%wt (°C)	T_{onset} 10%wt (°C)	T_{max} (°C)	ΔT_{onset} 5%wt (°C)	ΔT_{max} (°C)
Pure LLDPE	380,0	401,0	458,0	-	-
LLDPE + NPZnO 10000 ppm	427,0	442,0	476,0	47,0	18,0
LLDPE + EU 3000 ppm	432,0	447,0	479,0	52,0	21,0
LLDPE + EU/MMT-NPZnO 4,3%	396,0	416,0	463,0	16,0	5,0
LLDPE + EU/MMT-NPZnO 8,7%	417,0	435,0	475,0	37,0	17,0
LLDPE + EU/MMT-NPZnO 13.0%	434,0	448,0	478,0	54,0	20,0

Table 3. Results obtained from thermogravimetric analyses.

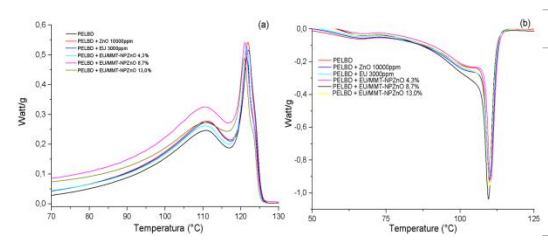


Figure 6. Differential scanning calorimetry curves of all films during the second heating (a) and cooling (b).

ID	Tm (°C)	Tc (°C)	ΔHm (J/g)	ΔHc (J/g)	C (%)
Pure LLDPE	121	110	101.14	-102.95	34.50
LLDPE + NPZnO 10000 ppm	121	110	121.45	-106.75	41.85
LLDPE + EU 3000 ppm	122	110	120.30	-100.42	41.16
LLDPE + EU/MMT-NPZnO 4,3%	121	110	118.01	-88.53	40.76
LLDPE + EU/MMT-NPZnO 8,7%	122	109	169.70	-109.37	58.35
LLDPE + EU/MMT-NPZnO 13.0%	121	110	147.03	-95.75	51.23

Table 4. Results obtained from differential scanning calorimetry analyses.

Figure 7. Bacterial inhibition curves of the LLDPE film and the LLDPE film containing the highest concentration of the EU/MMT-NPZnO additive.

ID	Deformação Máx. (%)	σDef. (%)	Tensão Máx. (Mpa)	σTens. (MPa)
Pure LLDPE	810,29	22,89	32,46	3,39
LLDPE + NPZnO 10000 ppm	555,52	51,19	28,03	5,86
LLDPE + EU 3000 ppm	674,00	52,00	34,00	8,00
LLDPE + EU/MMT-NPZnO 4,3%	590,13	77,06	15,77	3,49
LLDPE + EU/MMT-NPZnO 8,7%	394,70	35,86	13,42	4,42
LLDPE + EU/MMT-NPZnO 13.0%	416,40	63,71	13,51	2,50

Table 4. Results of tensile mechanical tests performed on the films.

Conclusions

EU/MMT-NPZnO was successfully incorporated into LLDPE films, improving thermal stability and crystallinity. Although mechanical properties decreased, the film containing 13.0% nanocomposite exhibited antibacterial activity against Staphylococcus aureus. These results highlight the potential of EU/MMT-NPZnO for antibacterial food packaging, warranting further studies on additive dispersion, mechanical performance, and antibacterial efficacy.

References & Acknowledgements

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