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The stability performances of epoxy resin-based monolayers on resisting disruption of temperature and wind

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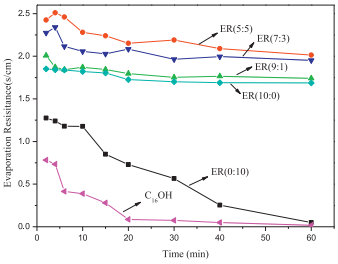
HIGHLIGHTS

- ER monolayers were prepared via the reaction of epoxy resin and alcohols.
- ER monolayers displayed better performance on resisting disruption.
- ER monolayers had a good effect on retardation of water evaporation.
- Energy barrier theory had been performed to explain retardation mechanisms.
- The disruption of wind was investigated by simulating the surface waves.

GRAPHICAL ABSTRACT

Plot of the evaporation resistance of $C_{16}OH$ and ER monolayers as a function of action time of the vertical vibration. The amplitude of the vertical vibration is 2 mm. The vibration frequency is 30 Hz. The temperature of subphase water is 303 K.



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ABSTRACT

In this paper, epoxy resin-based monolayers (ER monolayers) were prepared as water evaporation retardants. The interfacial stability performances of molecular films on resisting disruption of temperature and wind were investigated. The dependence of evaporation resistance on temperature was explicit and supported. Energy barrier theory was performed to explain the retardation mechanism of water evaporation of ER monolayers. The disruption of wind on monolayers was researched through simulation of surface waves over the subphase water. The results showed that ER monolayers presented better stability to resist disturbances of temperature shift and surface waves compared to $C_{16}OH$ monolayer. ER monolayers had a good effect on retardation of water evaporation due to their ability to spread spontaneously and form closely packed films over the water surface.

1. Introduction

Water is an essential resource for human survival and development. In areas which suffer from drought and water scarcity, evaporation capacity is several or dozens of times of local rain precipitation, or even hundreds of times in fewer regions. In order to reduce the evaporative loss of water bodies, the most feasible method is to spread evaporation retardants over the water surface [1]. Water evaporation retardants can spread spontaneously to form insoluble monolayers over the water surface and inhibit water exposure into the air, which retard the evaporation of water effectively [2,3].

The materials of molecular films are straight-chain fatty alcohol (C_{16}–C_{22} alcohol), straight-chain fatty acid (C_{17}–C_{20} acid), which are most frequently researched as evaporation retardants in previous literatures [4,5,2,6]. These materials can form dense monolayers at the air/water interface, which effectively inhibit water evaporation. However, the widespread application of monolayers in commercial is unsuccessful up to now due to their poor mechanical performances. Their molecular films are prone to bust

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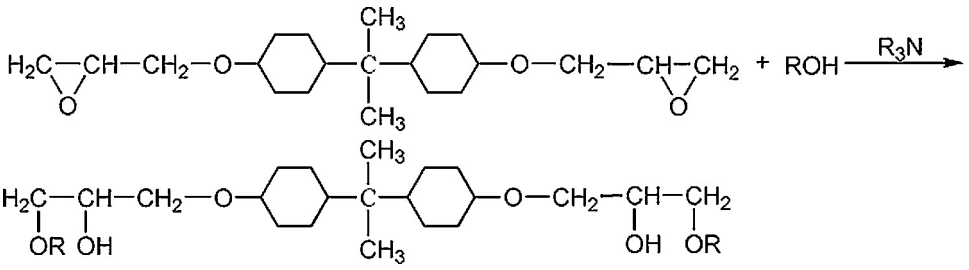

Scheme 1. Synthetic chemical equation to produce epoxy resin compounds.

up on exposure to temperature shift and wind action [7–9]. Once ruptured, these monolayers are difficult to reconstruct, and further, the inhibiting effects have been lost. Therefore, it is of great urgency to research new types of film-forming materials that has good mechanical performances.

According to some studies, the addition of polymers to the monolayers of fatty alcohols has been considered as a method to improve the wind resistance of the monolayers, the polymers could be poly(vinyl stearate) poly(octadecyl acrylate) or poly(octadecyl methacrylate) [10–14]. The results showed that the composites had good performances, which combined the mechanical strength of the polymers with the evaporation resistance of fatty alcohols. However, the improved wind stability could be observed in the composites at the expense of poorer water evaporation resistance.

In this paper, hydrogenated bisphenol A epoxy resin had been introduced into 1-hexadecanol to enhance the mechanical strength and tenacity of the monolayers, because epoxy resin had good mechanical properties and weather resistance. Epoxy resin-based monolayers (ER monolayers) were synthesized via the reaction of hydrogenated bisphenol A epoxy resin and long/short chain alcohols. The effect of the molar ratio of 1-hexadecanol in ER on the properties of monolayers, such as temperature resistance, wind resistance and evaporation resistance was investigated, respectively. In order to investigate the dependence of evaporation resistance of ER monolayers on the temperature of subphase water, energy barrier theory had also been performed to explain retardation mechanisms, which was responsible for the properties of ER monolayers with different molecular structures. In order to accurately reflect actual effect of wind on monolayers, the disruption of wind was investigated by simulating the surface waves over the water surface.

2. Materials and methods

2.1. Materials

Hydrogenated bisphenol A (HBPA) (≥99%, AR) was purchased from Puyang Huicheng Co., Ltd., which was purified by recrystallization from acetone solution. 1-Hexadecanol $C_{16}H_{33}OH$ ($C_{16}OH$) (≥99%, AR) was obtained from Guangfu Fine Chemical Research Institute, which was also purified by recrystallization from *n*-hexane solution for five times. 1-Butanol C_4H_9OH (C_4OH) (≥98%, AR) was obtained from Tianjin No.3 Chemical Factory, which was purified by distillation to cut fraction of 390–391 K.

Other chemicals were epoxy chloropropane, dodecyl tertiary amine, stannic chloride, toluene, diethyl ether, ethyl acetate and petroleum ether (boiling range 303–333 K fraction), which were the reagent grade; all of them were purchased from Tianjin, China and used directly without further purification. Subphase water was the ultrapure water with 18.2 MΩ cm^{-1} resistivity at 298 K, which was made by using Ellx5 Milli-Q of Merck Millipore.

Table 1
List the epoxy group content of the products.

ER	Molar ratio a:b:c	Epoxy value (mol/100 g)	Epoxy group content (%)
ER (10:0)	5:10:0	0.051	2.19
ER (9:1)	5:9:1	0.048	2.06
ER (8:2)	5:8:2	0.051	2.19
ER (7:3)	5:7:3	0.052	2.24
ER (6:4)	5:6:4	0.054	2.32
ER (5:5)	5:5:5	0.055	2.37
ER (4:6)	5:4:6	0.080	3.44
ER (3:7)	5:3:7	0.096	4.13
ER (2:8)	5:2:8	0.158	6.79
ER (1:9)	5:1:9	0.210	9.03
ER (0:10)	5:0:10	0.222	9.55

A is hydrogenated bisphenol A epoxy resin, B is 1-hexadecanol, and C is 1-butanol.

2.2. Synthesis of epoxy resin compounds (ER)

12 g of HBPA, 23 g of epichlorohydrin and 0.53 g of stannic chloride ($SnCl_4$) were reacted for 4 h at 323 K. After that, 6 g of sodium hydroxide (NaOH) with the concentration of 30% (wt.%) was added into the mixture, and they were stirred at 323 K for 11 h. After that, 50 ml of distilled water was added and mixed thoroughly, then they were poured into a separatory funnel for static layering, the water layer was removed. The remaining solution was reacted at 343 K for 3 h, keeping constant temperature and adding 2.5 g of 30% (wt.%) of sodium hydroxide (NaOH) aqueous solution, and then 30 ml of distilled water was added to wash until the pH of the separated aqueous layer was neutral. After completion of the reaction, the reaction product was purified by dissolving in toluene solution to remove hydrogenated bisphenol A and distilling to remove epoxy chloropropane. The product was clear and transparent viscous liquid, and the yield was about 60%. The epoxy value was 0.490 (mol 100 g^{-1}) measured by the hydrochloride-acetone method.

$C_{16}OH$, C_4OH and hydrogenated bisphenol A epoxy resin were reacted at 373 K under reflux condensation for 24 min by taking organic alkali-tertiary amine as an initiator. The reaction products were purified by washing with diethyl ether to remove $C_{16}OH$ and C_4OH. The final products of epoxy resin compounds (ER) were white solid. The characterization of the products showed that hydrogenated bisphenol A epoxy resin was modified by different molar ratios of 1-hexadecanol and 1-butanol, which was proved by FT-IR, ^{1}HNMR and the hydrochloric acid-acetone titration. The results of detection proved that the final products contain epoxy group with the amount of 2–10%, which is shown in Table 1.

In Scheme 1, R is R_1 ($C_{16}H_{33}$) or R_2 (C_4H_9). In subsequent part, ER (a:b) means R_1 : R_2 = a:b (mol), e.g. ER (5:5) equals that the molar ratio of 1-hexadecanol and 1-butanol is 5:5.

2.3. Characterization of products

The products in this work were characterized by nuclear magnetic resonance (NMR) on a Bruker 400M Spectrometer for ^{1}HNMR.