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COMPARATIVE STUDY ON THE FENTON OXIDATION OF GALLIC ACID AND CATECHOL IN AQUEOUS SOLUTIONS

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Introduction

Republic of Moldova is a predominantly agricultural country where the food industry, despite its economic importance, generates wastewater containing non-biodegradable pollutants that impair natural water quality. Among these, phenolic compounds such as gallic acid (GA) and catechol (1, 2-dihydroxybenzene) are of particular concern. Their presence in effluents affects aquatic ecosystems by reducing oxygen levels, altering biodiversity, and promoting eutrophication. Moreover, both compounds exhibit acute and chronic toxicity toward fish, algae, and humans through contaminated water, while the disinfection of GA-containing waters may lead to carcinogenic by-products. Due to their persistence and ecological risks, the removal of GA and catechol from wastewater is essential. The aim of this work was to investigate the efficiency of catalytic oxidation via the homogeneous Fenton process for the removal of gallic acid and catechol from aqueous solutions. The originality of the study lies in the comparative evaluation of two structurally related phenolic pollutants under controlled experimental conditions, providing new insights into their degradation kinetics and mineralization pathways. Furthermore, the research addresses the local context of the Republic of Moldova, where such pollutants are relevant due to agro-industrial and chemical activities, thus supporting the applicability of advanced oxidation processes for regional wastewater treatment challenges. To the best of our knowledge, this is the first comparative study of GA and catechol degradation by Fenton oxidation conducted in the context of Moldovan wastewater streams.

Materials and methods

Gallic acid ($C_7H_6O_5$) and catechol ($C_6H_6O_2$) were selected as target compounds due to their structural similarities and environmental relevance. All chemicals were of analytical grade and used without further purification. Batch experiments were carried out in a 500 mL glass reactor under constant stirring. The initial concentration of each pollutant was set at 50 mg/L (0.29 mmol/L for gallic acid and 0.45 mmol/L for catechol). The catalytic reactions were initiated by adding hydrogen peroxide (H_2O_2, 30%) to the aqueous solution, maintaining a molar ratio $H_2O_2 : Fe^{2+} = 10 : 1$. The pH was adjusted to 3 using sulfuric acid, optimal for

Fenton reactivity. Samples were taken at 0, 5, 15, 30, and 60 min and immediately quenched with methanol to stop the reaction.

Residual pollutant concentration was measured by UV-Vis spectrophotometry (λ = 272 nm for gallic acid, 275 nm for catechol). Mineralization was assessed via chemical oxygen demand (COD), using the dichromate method.

Results and conclusions

The comparison of gallic acid and catechol under homogeneous Fenton conditions shows that both compounds undergo rapid initial degradation. However, gallic acid exhibits higher efficiency, achieving faster removal and deeper mineralization, while catechol degrades more slowly and forms persistent intermediates. After 15 min, gallic acid reached 91% degradation, while catechol achieved 75%. At 60 min, gallic acid was almost completely removed (98%), whereas catechol degradation was slightly lower (88%). Mineralization, evaluated through COD reduction, also showed a clear difference: gallic acid reached 68% COD removal, compared to only 50% for catechol. This indicates that gallic acid not only degraded faster but was also mineralized more completely, while catechol generated more persistent intermediates that resisted further oxidation. To further clarify the reaction dynamics, kinetic parameters were determined assuming pseudo-first-order kinetics (Table 1). The calculated rate constant (*k*) for gallic acid (0.112 min^{-1}) was significantly higher than that for catechol (0.073 min^{-1}), confirming the faster reaction rate. This trend is reflected in the half-life values: gallic acid exhibited a shorter half-life of 6.2 min, compared to 9.5 min for catechol. Moreover, the initial reaction rate of gallic acid (0.026 $\text{mmol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$) exceeded that of catechol (0.020 $\text{mmol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$), highlighting its greater susceptibility to oxidative attack.

Table 1. Kinetic parameters for Fenton oxidation of gallic acid and catechol

Parameters	**Gallic Acid**	**Catechol**
Initial concentration ($\text{mmol}\cdot\text{L}^{-1}$)	0.29	0.45
Rate constant k (min^{-1})	0.112	0.073
Initial reaction rate ($\text{mmol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$)	0.026	0.020
Half-life $t_{1/2}$ *(min)*	6.2	9.5

This study comparatively evaluated the degradation and mineralization of gallic acid and catechol in homogeneous Fenton oxidation. Gallic acid exhibited faster kinetics ($k = 0.112\ \text{min}^{-1}$; $t_{1/2} = 6.2$ min) and higher mineralization (68% COD reduction), attributed to its reactive molecular structure. Catechol, despite showing substantial degradation, reached lower mineralization efficiency (50% COD reduction) due to the accumulation of stable semi-quinonic intermediates. The superior mineralization of gallic acid indicates that the homogeneous Fenton process is particularly effective for tri-hydroxybenzoic compounds. However, the persistence of partially oxidized intermediates in catechol oxidation highlights the need for process intensification. Strategies such as photo-Fenton, combined advanced oxidation processes (AOPs), or catalyst modification may enhance catechol mineralization. From an applied perspective, these findings suggest that wastewater streams enriched in gallic acid may be more efficiently treated under standard Fenton conditions, while catechol-containing effluents may require hybrid or sequential processes.

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