DOI: http://doi.org/10.21698/simi.2025.ab19

REDUCTION OF WATER HARDNESS USING LEMON PEEL AS A NATURAL BIOADSORBENT

Marilena-Valentina Stînga, Nicoleta Vasilache, Antonia Ioana Cimpean, Iuliana Paun, Florentina Laura Chiriac

National Research and Development Institute for Industrial Ecology- ECOIND, 57-73 Drumul Podu Dambovitei, district 6, 060652 Bucharest, laura.chiriac@incdecoind.ro, Romania

Keywords*: adsorption isotherm, biosorbent, lemon peel, water hardness*

Introduction

Hardness in water, primarily caused by calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, is a major concern in both domestic and industrial water systems. It leads to scale deposits in pipelines, reduces the efficiency of heat exchangers, and interferes with cleaning processes. Inactive or dead microbial biomass has the ability to retain calcium (Ca) and magnesium (Mg) metal ions through various physicochemical processes, making biosorption a promising method for their removal from water. Recent research has shown that the chemical structure of microbial cells involved in the biosorption process plays a key role in its efficiency. Some biomaterials exhibit a high capacity for metal binding, and certain types of biosorbents can adsorb a wide range of multivalent metal cations, while others are specialized in retaining specific metals. Traditional methods such as ion exchange or chemical softening are effective but generate waste and increase treatment costs. In recent years, biosorption has emerged as a promising, eco-friendly technique using waste-derived materials capable of capturing divalent metal ions from aqueous media. The peels were subjected to simple treatments (drying, grinding, washing) and chemical/thermal pretreatments (acid, NaOH, carbonization) to enhance adsorption efficiency. Among biosorbents, lemon peel a commonly available organic waste shows potential due to its content of functional groups like carboxylic, hydroxyl, and carbonyl moieties, which facilitate ion exchange and complexation with Ca^{2+}. This study investigates the influence of key parameters (pH, contact time, biosorbent dose) on the efficiency of Ca^{2+} removal from synthetic hard water using lemon peel powder. The goal is to validate this material as a viable alternative to conventional methods in water hardness reduction.

Materials and methods

Biosorption is analyzed as a method for metal removal, based on the ability of biologically-derived materials to bind with them. Lemon peel is used as a biosorbent material for the removal of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions from water, by optimizing the dosage and particle size. Biomaterials are employed in the biosorption process as part of a modern and cost-effective treatment solution. Synthetic hard water solutions were prepared with calcium ion concentrations representative of moderate to high hardness levels (up to 5°dH). The lemon peel was oven-dried, ground to a fine powder, and used in batch adsorption experiments. Variables such as biosorbent mass (25 - 200 mg), pH (2 - 10), and contact time (0 - 300 min) were tested to evaluate their effect on adsorption performance.

The adsorption capacity (Q) was calculated from the difference between initial and final Ca^{2+} concentrations, measured via EDTA titration. Adsorption data were fitted to Langmuir and Freundlich isotherms, while kinetics were modelled using pseudo-first- and pseudo-second-order equations. All experiments were conducted in triplicate to ensure reproducibility.

Results and conclusions

Results showed that pH had a strong influence on Ca^{2+} adsorption. At acidic pH (2 - 4), adsorption was minimal, likely due to competition between H^+ and Ca^{2+} ions for binding sites. Maximum adsorption occurred at pH 8, reaching 7.76 mg/g. This trend aligns with the deprotonation of functional groups, which enhances electrostatic interactions with metal ions. Contact time also affected adsorption: a rapid increase in the first 60 minutes was followed by gradual equilibrium, indicating that initial adsorption occurs on external active sites, while further uptake involves slower intraparticle diffusion.

Langmuir model best described the equilibrium data (Qmax = 5.87 mg/g, R^2 = 0.9948), suggesting monolayer adsorption. Freundlich fit was weaker (R^2 = 0.7969), indicating a less heterogeneous surface. Kinetic analysis favored the pseudo-first-order model (R^2 = 0.9901), supporting the hypothesis that physical adsorption predominates. A 3 g dose of biosorbent removed approximately 42 % of the water hardness, with efficiency increasing proportionally with the applied dose.

These findings suggest that lemon peel, a low-cost and renewable material, can be effectively used to reduce water hardness in small- to medium-scale applications. Its effectiveness, combined with environmental benefits such as waste valorization and reduced chemical use, supports its integration into sustainable water treatment strategies.

For the Langmuir model, the maximum adsorption capacity (Q_{max}) was 5.87 mg/g, indicating the upper limit of the amount of calcium that can be retained on the adsorbent surface. The Langmuir constant (K_L) is 0.64 L/mg, suggesting a moderate affinity between Ca^{2+} ions and the surface of the lemon peel. An important aspect is the high correlation coefficient (R^2 = 0.9948), which confirms an excellent fit of the Langmuir model to the experimental data. This result indicates that the adsorption process predominantly follows the Langmuir mechanism, meaning the formation of a monolayer of Ca^{2+} ions on the adsorbent surface, with no significant interactions between the adsorbed molecules.

In the case of the pseudo-first-order kinetics, the rate constant k_1 is 5.93×10^{-5} min^{-1}, and the correlation coefficient R^2 is 0.9901. These values suggest a very good correlation between the experimental data and the first-order kinetic model, indicating that this model accurately describes the adsorption process.