Adsorptive Performance of Lemon Peel Powder in Textile Effluent Treatment in Removal of Lead (Pb): Langmuir and Freundlich Isotherm Studies

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ABSTRACT

An important environmental and public health concern is the release of untreated textile effluents that include dangerous heavy metals. This study explores the biosorption potential of Citrus limon (lemon) peel powder (CLPP) for the removal of heavy metals from textile wastewater to find affordable and sustainable treatment solutions. The lemon peels, an abundant Agro-waste, were processed into fine powder and characterized for their biosorptive properties. To assess their impact on metal uptake, batch biosorption tests were carried out with different contact times, pH levels, biosorbent dosages, and initial metal ion concentrations. To comprehend the interaction between the biosorbent and the metal ions, the equilibrium data were analyzed using the Langmuir and Freundlich adsorption isotherm models. The results demonstrated a high affinity of Citrus limon peel powder for the targeted heavy metals, with maximum sorption capacities aligning well with the Langmuir model, indicating monolayer adsorption. This study highlights the efficacy of lemon peel waste as an eco-friendly, cost-effective biosorbent for textile wastewater treatment and provides a theoretical foundation for future scale-up and application.

Keywords: Adsorption isotherm, Biosorption, Citrus limon peel powder, Freundlich model heavy metal removal, Langmuir model.

1. INTRODUCTION

The exponential growth of industrialization has resulted in the significant release of hazardous pollutants into aquatic environments, particularly from textile industries. Heavy metals are a major worry among the many toxins released because of their toxicity, inability to biodegrade, and propensity to accumulate in living things. These metals can cause severe environmental degradation and pose significant health risks to humans, including neurological, renal, and carcinogenic effects. Despite their effectiveness, conventional treatment techniques such chemical precipitation, ion exchange, membrane filtration, and electrochemical treatments frequently have drawbacks like high operating costs, insufficient removal, the production of secondary pollutants, and difficult sludge handling.

Studies have indicated that Citrus limon peel can exhibit high biosorption capacities for various heavy me tals, making it a viable candidate for treating textile effluents. The presence of multiple metal ions in textile wastewater introduces competition for binding sites on the biosorbent, necessitating an in-depth evaluation of biosorption performance under multi metal systems. Additionally, a few variables, such as pH, contact time, initial metal concentration, and biosorbent dosage, affect biosorption effectiveness and need to be methodically tuned for successful use.

The textile industry generates significant amounts of wastewater containing heavy metals. These metals pose serious environmental and health risks, necessitating effective removal techniques [2]. Adsorption is a promising method for heavy metal removal, with citrus limon peel powder (CLPP) emerging as a potential adsorbent due to its high surface area and functional groups [3]. The textile industry is a significant contributor to water pollution, with heavy metals such as being major contaminants [1]. Adsorption is a promising technique for removing heavy metals from wastewater [2]. Citrus limon peel powder (CLPP) is a potential adsorbent due to its high surface area and functional groups [3]. This study investigates CLPP's adsorption capacity for Pb removal from textile effluent and evaluates the applicability of Langmuir and Freundlich isotherm model [4]. The results of this study can contribute to the development of sustainable wastewater treatment systems [5]. CLPP's potential as an adsorbent is attributed to its abundant availability, low cost, and eco-friendly nature [6]. The adsorption process is influenced by various factors, including pH, adsorbent dose, and contact time [7]. Understanding the adsorption mechanism and kinetics is crucial for optimizing the process [8]. This study aims to provide insights into CLPP's adsorption capacity and its potential application in textile wastewater treatment.

2. SUPPLIES AND TECHNIQUES

2.1 Gathering of Samples

For the study of this effective biosorption on textile effluent, different samples from different places were collected from Kasipalayam (11.1155ºN, 77.3850º E), V. Kallipalayam (11.068347ºN, 77.312785ºE) and, Iduvampalayam (11.0819ºN, 77.3238ºE) at Tirupur City. Samples were collected in clean, 5 Litre sterilized polyethylene Canes and stored at 4°C until analysis to preserve sample integrity.

2.2 Preparation of Biosorbent

CLPP was prepared from dried citrus limon peels and characterized [9]. Textile effluent was collected from a local textile industry and analysed for Pb concentrations [10]. Batch mode adsorption tests were carried out with different adsorbent doses, contact times, and pH [11]. The adsorption data were subjected to Freundlich and Langmuir isotherm models [12]. The adsorption capacity of CLPP was evaluated based on the removal efficiency of Pb [13].

2.3 Biosorption Study

After taking a sample of the effluent, the biosorbent is gradually added in dosages ranging from 0.5 to 2.5 grams, and the samples are left on a mechanical shaker for 60 minutes. The initial and the Final pH will be note down for analysing the percentage removal efficiency. Then the samples were tested on atomic adsorption spectrophotometer for analysing the heavy metal elements concentration.

Batch mode adsorption tests were carried out with different adsorbent doses, contact times, and pH [6]. The adsorption data were subjected to Freundlich and Langmuir isotherm models [7], [8].

3 OUTCOMES AND CONVERSATION

3.1 The impact of pH

Experiments were conducted to investigate the effect of pH (1–10), contact time (60–300 minutes), biosor bent dose (0.5–2.5 mg/L), and metal concentration (10–100 mg/L) on biosorption efficiency [9]. Metal ion concentrations were determined using Atomic Absorption Spectrophotometer (AAS) [11]. It was observed that no adsorption occurred between pH 1 and pH 5, and the maximum % removal efficiency of Pb was achieved at pH 5 with 2.0g of dose, or 84.43 (Fig. 1). Similar to the study [23], these interpretations of the steadily increasing percentage of adsorption for the anionic dyes onto lemon peel were made. The degree of ionization of dye molecules and the surface characteristics of the adsorbent varies depending on the pH values, which in turn affect the pace at which dyes biosorbent.

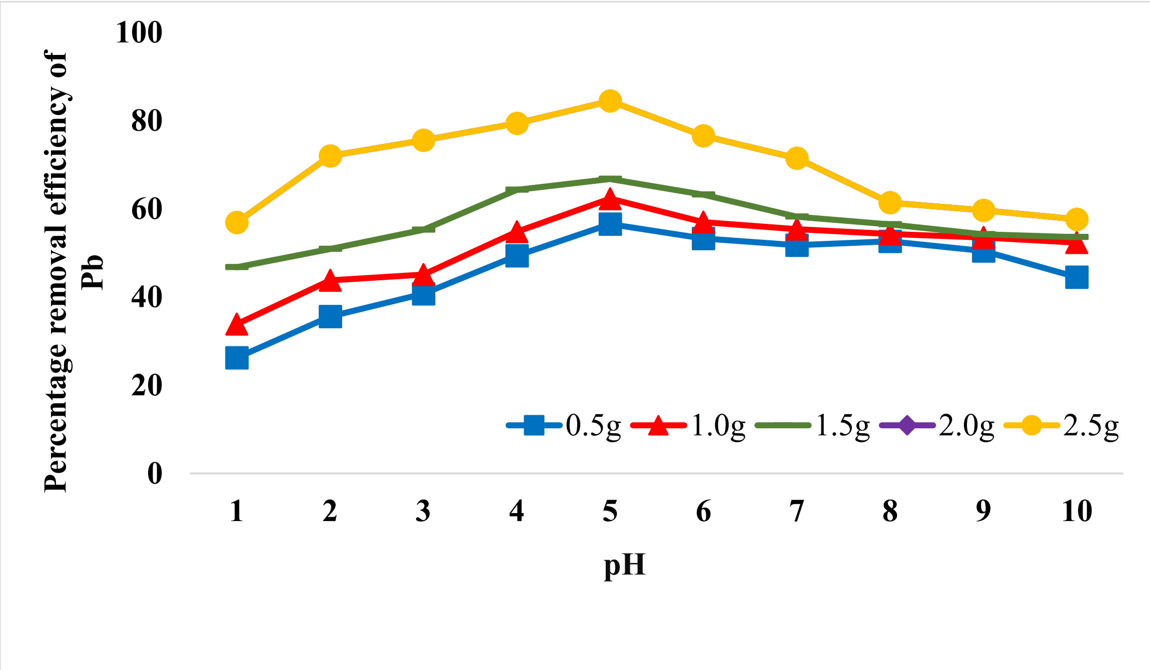

Fig. 1. Visual Display of pH Against Percentage removal efficiency of Pb metal ion by CLPP

3.2 Adsorbent Dosage Effect

Figure 2 illustrates the impact of varying the adsorbent dosage from 0.5 to 2.5g on the effluent. It is evident that the percentage of metal removal rises as the dosage of the biosorbents increases. The biosorbent and adsorption process of Pb was achieved for maximum percentage removal efficiency as with the dose amount of 2.0g. The percentage adsorption of metals onto Pb was 84.43 for the highest percentage removal efficiency at pH 5. The number of active sites available for adsorption rises with increasing adsorbent dosage, increasing the dye removal percentage. The maximum dosage of 2.0g resulted in the removal of the maximum efficiency of ions due to the increased availability of convertible locations, but the initial stages of dosage content in 0.5g had been 26.22, which began its removal efficiency.

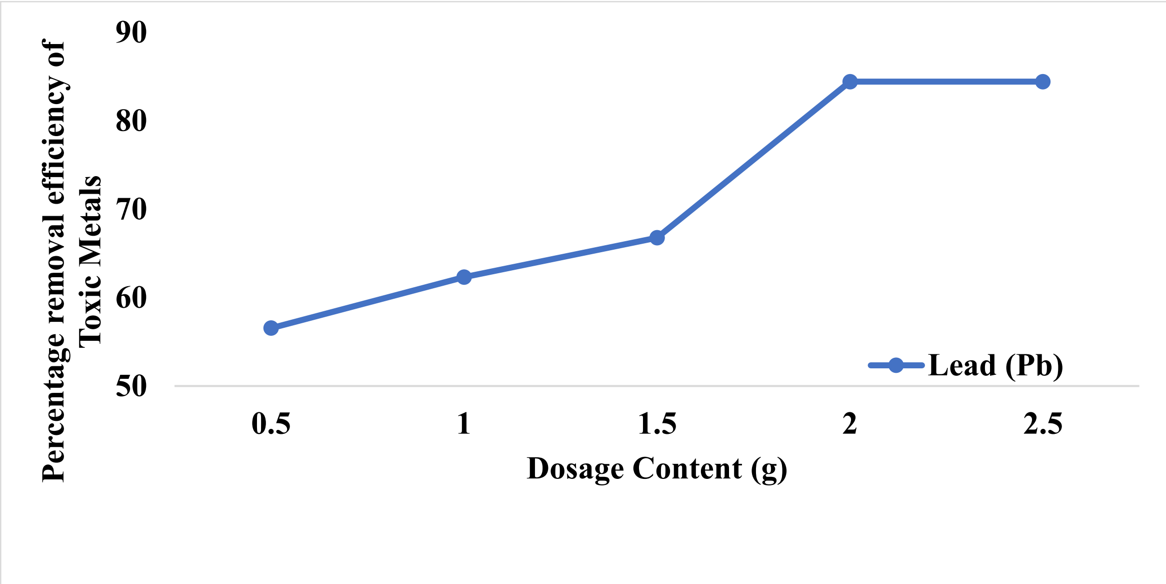

Fig. 2. Visual Display of Dosage content Against Percentage removal efficiency of Pb metal ion by CLPP at pH 5 (2.0g)

3.3 Impact of Contact Duration

The percentage of different heavy metals removed by the CLPP as a biosorbent was displayed in Fig. 3. There was an increase in the percentage of metal ions removed from the textile wastewater contact time for each of the metal ions present. The chemical attraction of the adsorbents for harmful ions might be used to explain the higher removal effectiveness with an increase in contact time. It is evident that the percentage of adsorption generally rose until it reached the maximum % removal efficiency of metals, which was achieved by Pb in 240 minutes at pH 5 with a dosage amount of 2.0g. After that, as it gets closer to equilibrium conditions, the process becomes relatively constant until equilibrium is reached at a specific moment.

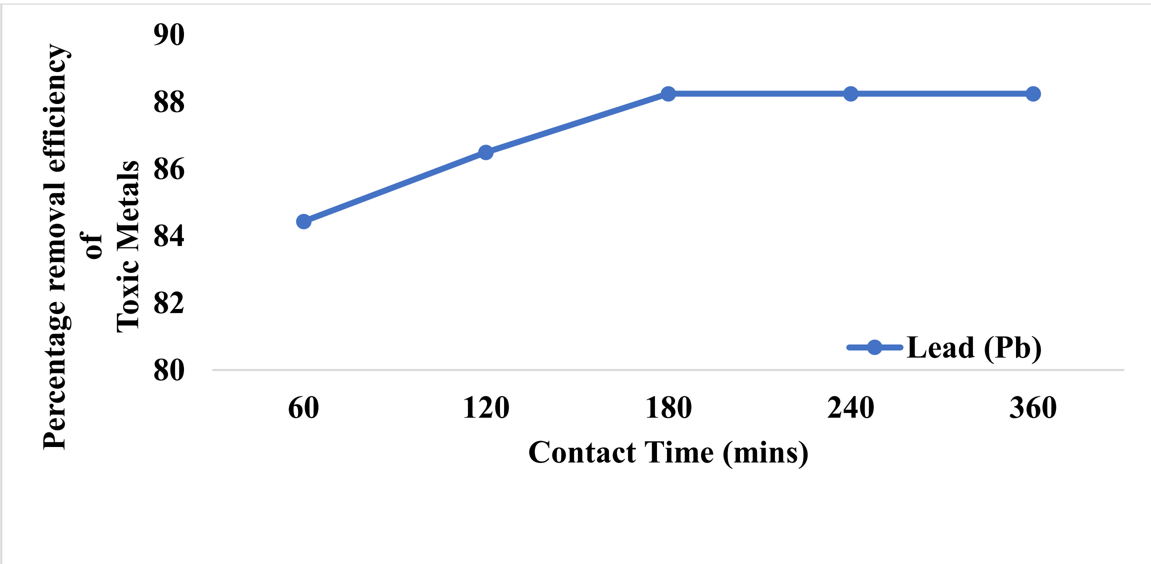

Fig. 3. Visual Display of Contact Time Against Percentage removal efficiency of Pb metal ion by CLPP at pH 5 (2.0g)

3.4 Isotherm Modelling

It was demonstrated by the regression analysis of the Langmuir isotherm parameters that the hazardous metals are represented by the biosorption equilibrium constant (b) and the maximum biosorption capacity per unit of biosorbent (q_{max}). The applicability of this model is demonstrated in the table by the correlation coefficient (R^2), which was found to be well suited for the Langmuir isotherm. 1. The adsorption system was predicted by the dimensionless separation parameter (R_L), which was favorable and showed the isotherm shape.

Figure 4 displays the Freundlich constants K and n, which were calculated from the slope and intercept of the linear plot with log q_e with respect to log C_e. K_F is a constant associated with adsorption capacity, and the magnitude of the component 'n' indicates the favourability of the adsorption process. From the equation of this model, the isotherm constants 'K' and 'n' were computed and suppressed. This procedure indicates that a value of n larger than unity indicates favorable biosorption.

The below results shows that the equilibrium adsorption data of Lead (Pb). The higher value of R^2 indicates that the Isotherm as the most favourable model for the CLPP.

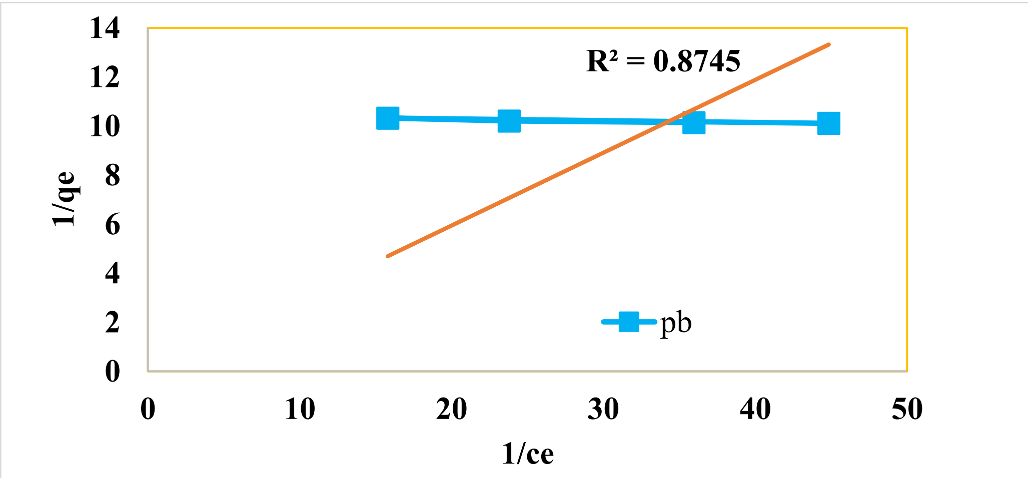

Fig. 4 Toxic Metal-Lead (Pb) analyzing using Langmuir Isotherm Plot

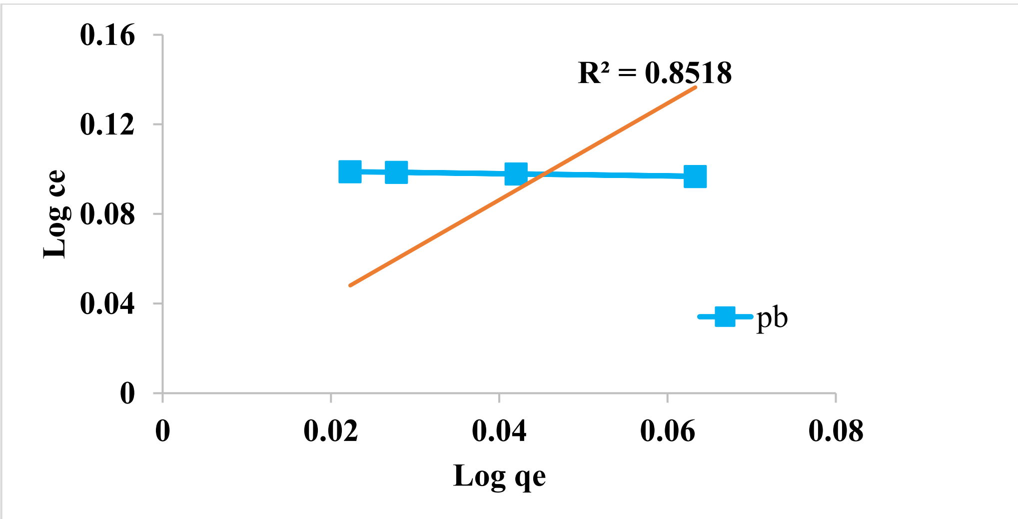

Fig. 5 Toxic Metal-Lead (Pb) analysing using Langmuir Isotherm Plot

Table.1. Aspects of the Isotherm Model for CLPP

Isotherm parameters	Metal Elements			
	Pb	Ni	Cr	Zn
Langmuir Isotherm				
R^2	0.9925	0.9903	0.9948	0.9939
R_L	0.0451	0.0385	0.0342	0.0362
q_{max} (mg/g)	24.31	17.89	19.72	21.78
b(l/mg)	0.172	0.254	0.289	0.275
Freundlich Isotherm				
R^2	0.981	0.9786	0.9864	0.984
n	2.44	2.68	2.6	2.55
K_F(mg/g)	3.9	2.78	3.05	3.38

4 FINAL RESULTS

The CLPP study's findings can be applied as an inexpensive adsorbent substitute for the removal of heavy metals from wastewater containing dyes. It is very effective and has a large adsorption capability. Citrus limon peels can be used in somewhat larger quantities to achieve total heavy metal elimination because they are easily accessible locally and reasonably priced. Because it is abundant, inexpensive, and effective, it may be supplied locally, making it a viable biomass option for the removal of Pb ions at pH 5 of dose. Its high adsorption capacity and favourable isotherm characteristics suggest its potential in wastewater treatment. Future work should focus on column studies and regeneration efficiency [6], [14]. As a result, environmental pollution can be decreased by removing heavy metals from wastewater. The Langmuir isotherms provide the best fit to the obtained results. This study demonstrates the potential of CLPP as an adsorbent for removing Pb and various elements from textile effluent. The results of this study can contribute to the development of sustainable wastewater treatment systems. CLPP's abundant availability, low cost, and eco-friendly nature make it a promising adsorbent for heavy metal removal. Further studies are needed to optimize the adsorption process and explore the scalability of CLPP for industrial applications.

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