Electronic Supplementary Material (ESI) for Environmental Science: Advances.

Industrial Biomass Waste as Economically Potential Adsorbents for Removing Bismarck Brown R Dye and Zinc Metal Ions from Effluents

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S1. Point of zero charge (pH_{PZC})

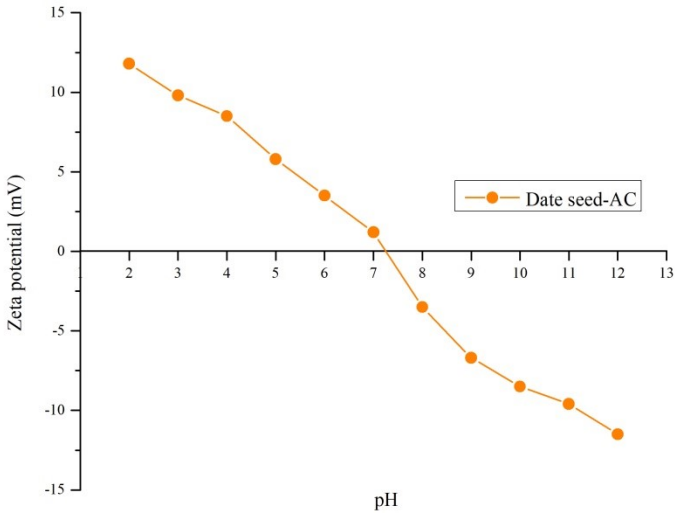

Figure S1. Zeta potential of date seed derived activated carbon with pH value.

The pH-dependent variation in the surface charge of DS-AC (Date Seed - Activated Carbon), as indicated by its point of zero charge, plays a crucial role in determining the adsorption behavior of ions in solution. This understanding of the surface charge characteristics of DS-AC is fundamental for optimizing its performance as an adsorbent in wastewater treatment processes. Figure S1 depicting the zeta potential and the point of zero charge (pH_{PZC}) specifically observed on the surface of DS-AC (Date Seed - Activated Carbon). The point of zero charge for DS-AC, as indicated by the data, is determined to be at 7.25. This pivotal point signifies the pH value at which the surface of the adsorbent carries no net charge.

When the pH of the solution is lower than the pH_{PZC}, the surface of the DS-AC exhibits an overall positive charge. This positive charge creates favorable conditions for the adsorption of anions (negatively charged ions) onto the surface of the adsorbent material. The electrostatic attraction between the positively charged surface sites of the DS-AC and the anions in the

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solution facilitates their adsorption onto the adsorbent's surface. Conversely, when the pH of the solution surpasses the pH_{PZC}, the surface of the DS-AC tends to become negatively charged. This negative charge results in the presence of negative sites on the adsorbent surface. Consequently, this configuration enables the adsorption of cations from the solution onto the surface of the DS-AC. The electrostatic interactions between the negatively charged surface sites of the adsorbent and the cations in the solution promote the adsorption process [1,2].

S2. Effect of adsorbent dose

The effect of adsorbent dose on DS-AC for the removal of BBR dye and Zn ions reveals valuable insights into the adsorption process. The adsorbent dose of 0.05 to 0.25 g/50 ml solution is used in the adsorption process, and its variation can impact the removal efficiency of contaminants.

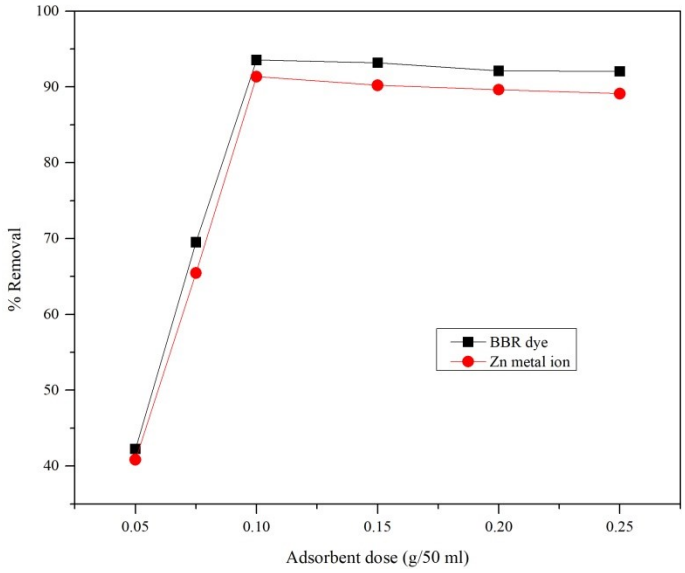

Figure S2. The effect of adsorbent dose for BBR and Zn removal (pH: 6, temperature: 40 ^{o}C, BBR concentration: 10 mg/L, Zn concentration: 100 mg/L, contact time: 120 min)

As shown in Fig S2 data illustrates the percentage removal of BBR dye and Zn ions at different adsorbent doses. As the adsorbent dose increases from 0.05 g to 0.25 g, the removal percentage of BBR dye consistently rises. The removal efficiency increases from 42.26% at the lowest dose to a peak of 93.56% at an adsorbent dose of 0.1 mg. Beyond 0.1 mg, the removal percentages remain relatively high, indicating a favorable performance of the activated carbon in removing the dye. Similar to the pattern observed for BBR dye, the removal of Zn ions also exhibits an increasing trend with higher adsorbent doses. The removal efficiency progresses from 40.83% at the lowest dose to a maximum of 91.36% at an adsorbent dose of 0.1 mg. Subsequent increases in the adsorbent dose result in relatively stable removal percentages, indicating a plateau in the efficiency of zinc ion removal. The data suggests that an adsorbent dose of 0.1 mg is particularly effective for both BBR dye and Zn ion removal. At this dosage, the removal percentages reach their highest values. The optimal dose, the removal percentages do not show significant

improvements, suggesting that there might be a point of diminishing returns where additional activated carbon does not substantially enhance removal efficiency.

S3. Effect of pH

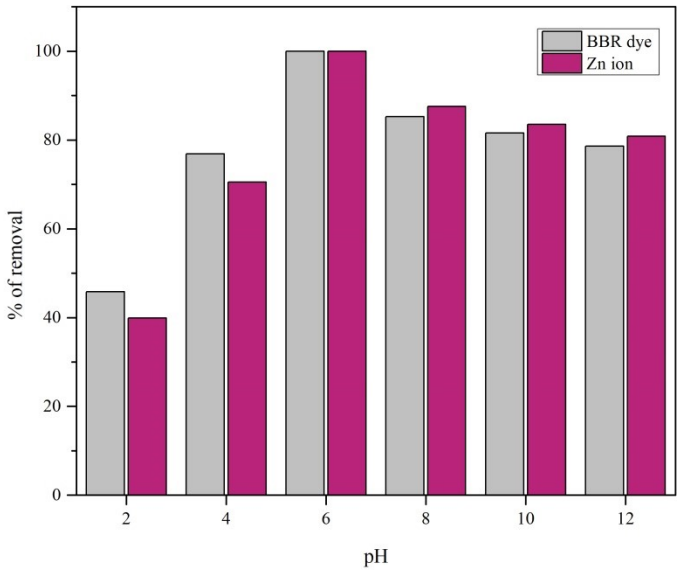

Figure S3. The effect of pH for BBR and Zn removal (adsorbent dose: 0.1 g/50ml, temperature: 40 ^{o}C, BBR concentration: 10 mg/L, Zn concentration: 100 mg/L, contact time: 120 min)

Figure S3 shows the percentage removal of BBR dye and Zn ions at different pH values ranging from 2 to 12. The effect of pH on DS-AC for the removal of BBR dye and Zn ions sheds light on the influence of solution acidity or alkalinity on the adsorption process. The removal percentage of BBR dye varies significantly with changes in pH. The removal efficiency is relatively low at pH 2 (45.85%) and gradually increases with increasing pH. The highest removal percentage is observed at pH 6 (99.99%), indicating an optimal pH condition for effective removal. After pH 6, the removal efficiency declines that suggesting a sensitivity of the adsorption process to pH changes. Similar to BBR dye, the removal efficiency of Zn ions is influenced by pH variations. The lowest removal percentage occurs at pH 2 (39.88%), and a gradual increase is observed with increasing pH. The highest removal percentage is again at pH 6 (99.99%), highlighting the optimal pH for efficient Zn ion removal. Similar to the dye, removal efficiency decreases at higher pH values. The data suggests that pH 6 is optimal for both BBR dye and Zn ion removal, with removal percentages reaching their highest values at this pH. The sensitivity of the adsorption process to pH variations is evident. The removal efficiency is influenced by the surface charge of the activated carbon and the ionization state of the contaminants, both of which are pH-dependent.

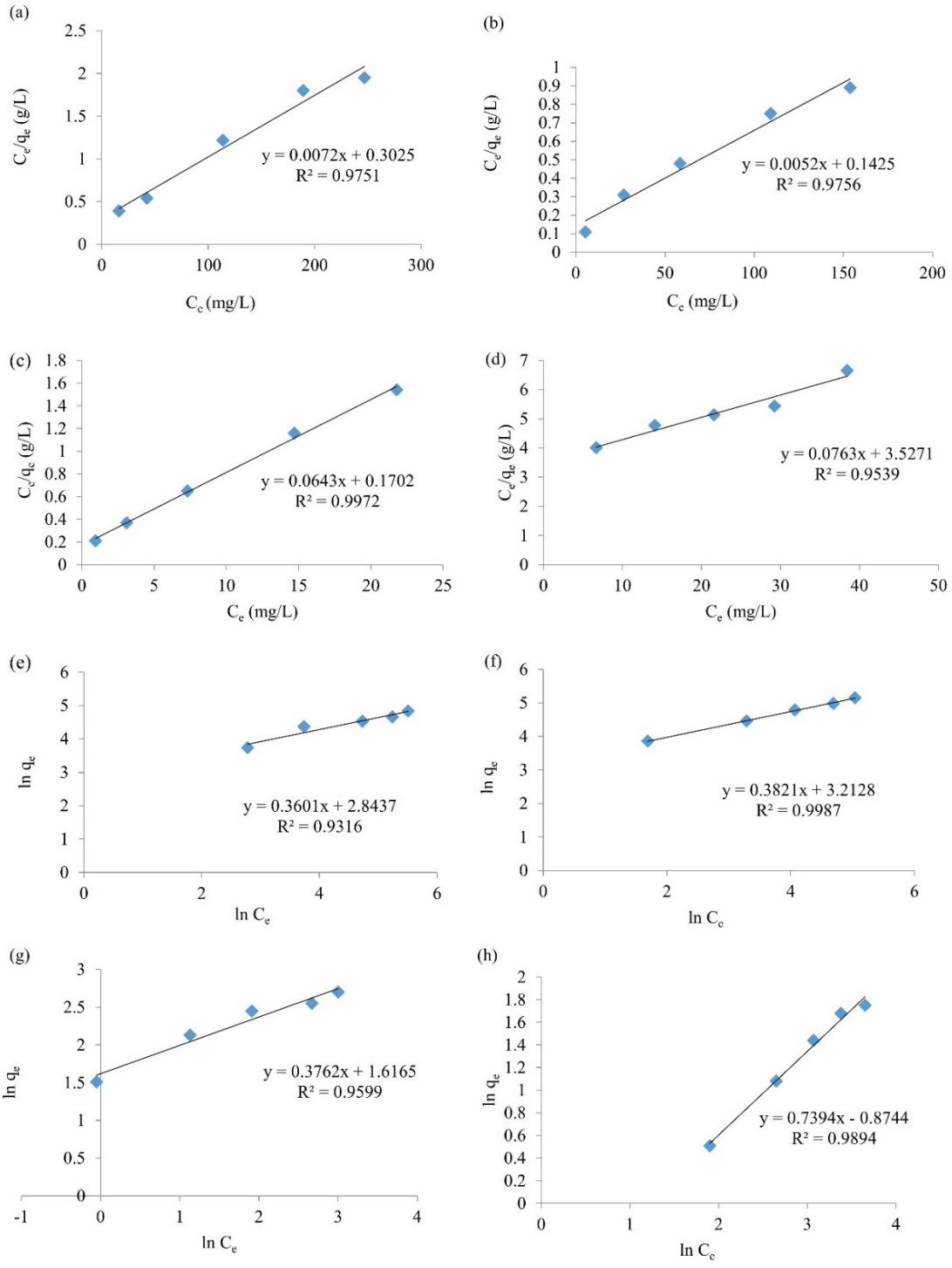

Figure S4. Langmuir Adsorption Isotherm fit (50 mL of dye solution/0.1 g of AC) for BBR dye adsorption on (a) AC 55 and (b) AC 65, Zn ions adsorption on (c) AC 55 and (d) AC 65, Freundlich Adsorption Isotherm fit for BBR dye adsorption on (e) AC 55 and (f) AC 65, Zn ions adsorption on (g) AC 55 and (h) AC 65. (pH 6, agitation 180 rpm, a temperature of 30°C and a contact time 120 minutes).

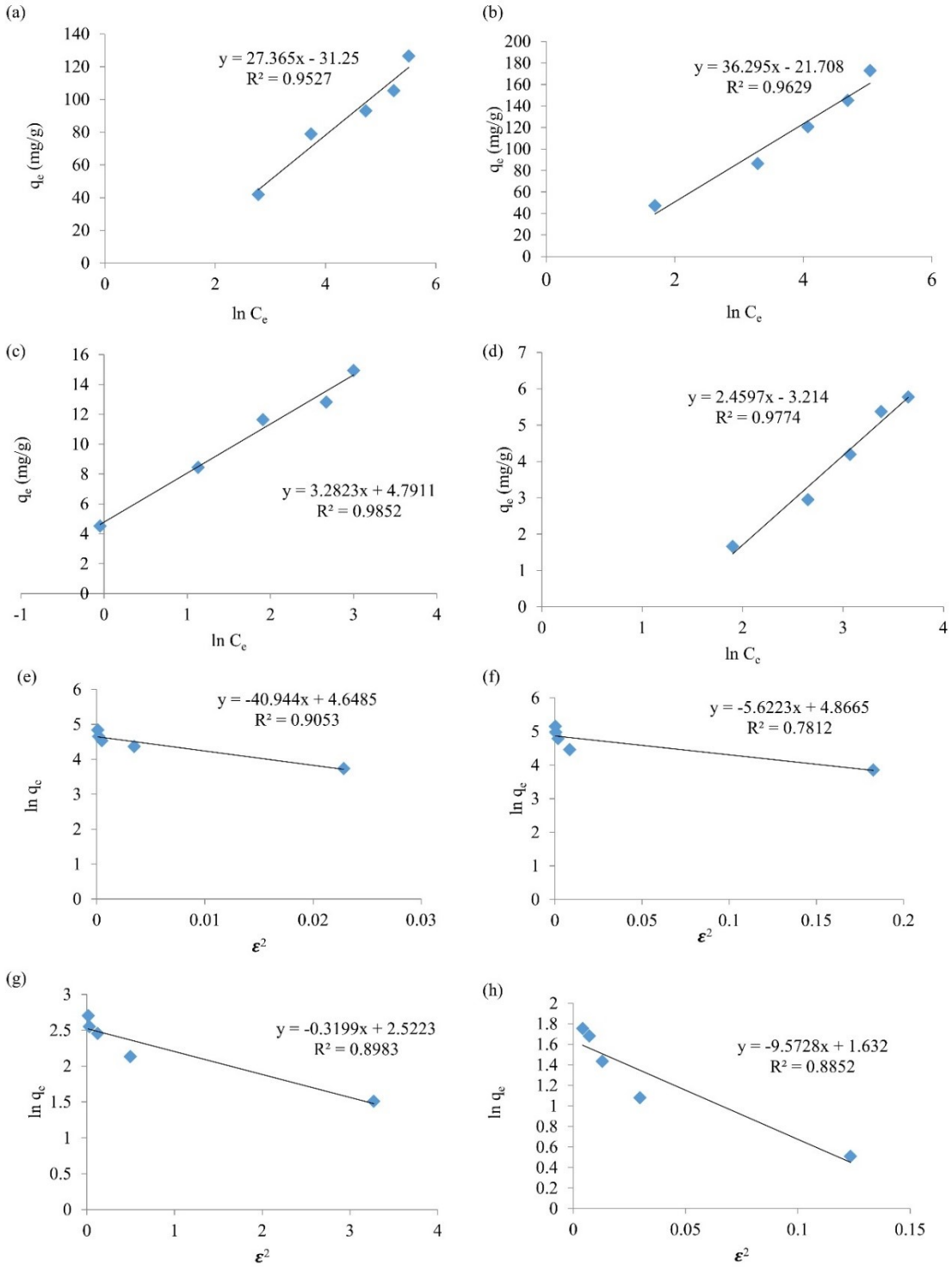

Figure S5. Temkin Adsorption Isotherm fit (50 mL of dye solution/0.1 g of AC) for BBR dye adsorption on (a) AC 55 and (b) AC 65, Zn ions adsorption on (c) AC 55 and (d) AC 65,

Dubinin-Radushkevich Isotherm fit for BBR dye adsorption on (e) AC 55 and (f) AC 65, Zn ions adsorption on (g) AC 55 and (h) AC 65. (pH 6, agitation 180 rpm, a temperature of 30°C and a contact time 120 minutes).

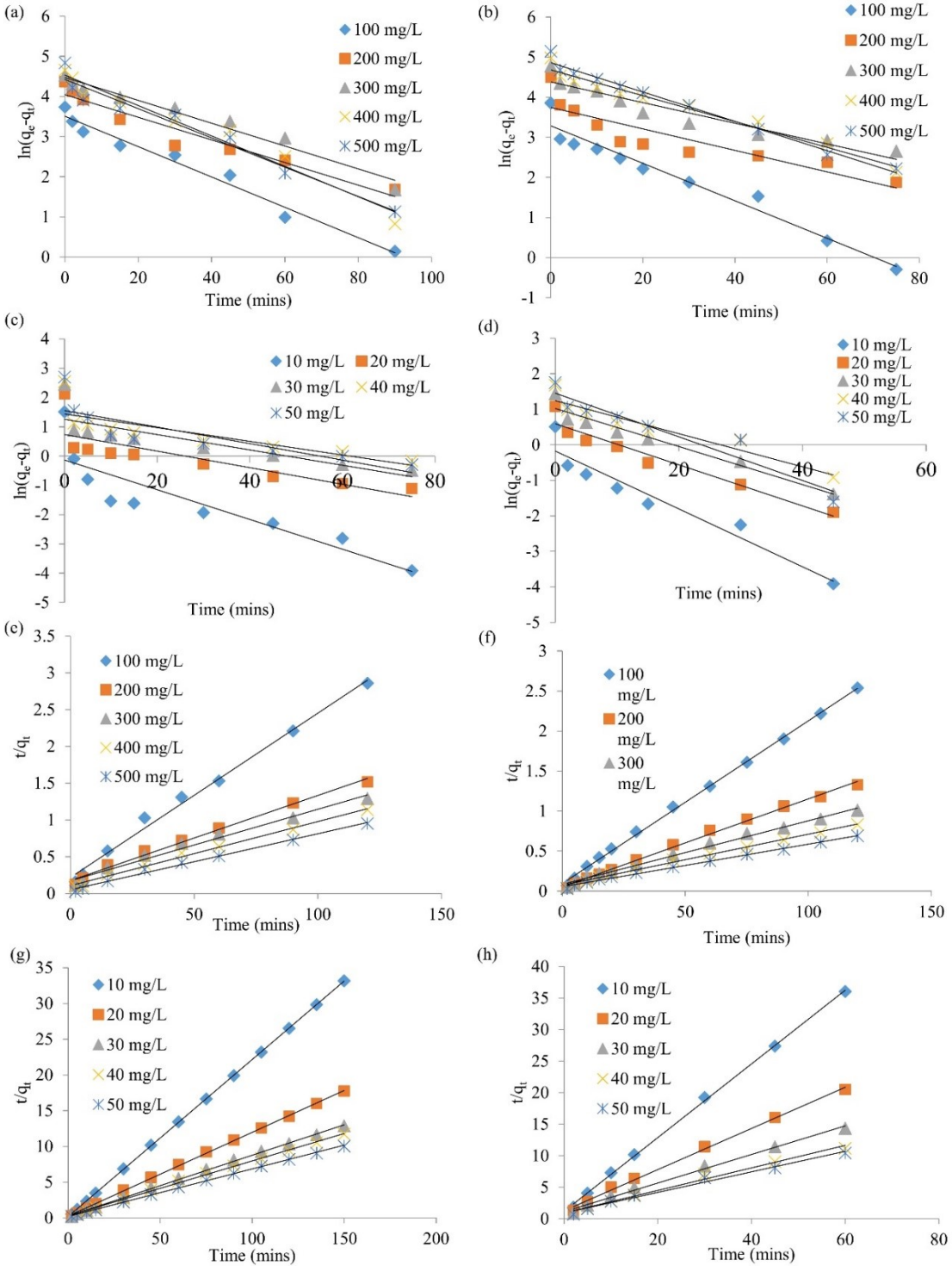

Figure S6. Pseudo-first-order kinetics model for BBR adsorption on (a) AC 55, (b) AC 65; For Zn adsorption on (c) AC 55, (d) AC 65. Pseudo second order kinetics model for BBR adsorption on (e) AC 55, (f) AC 65, for Zn adsorption on (g) AC 55, (h) AC 65. (pH 6, a contact time 120 minutes, agitation 180 rpm, a temperature of 30°C, and concentrations ranging from 100 to 500 mg/L for BBR and 10 to 50 mg/L for Zn ions)

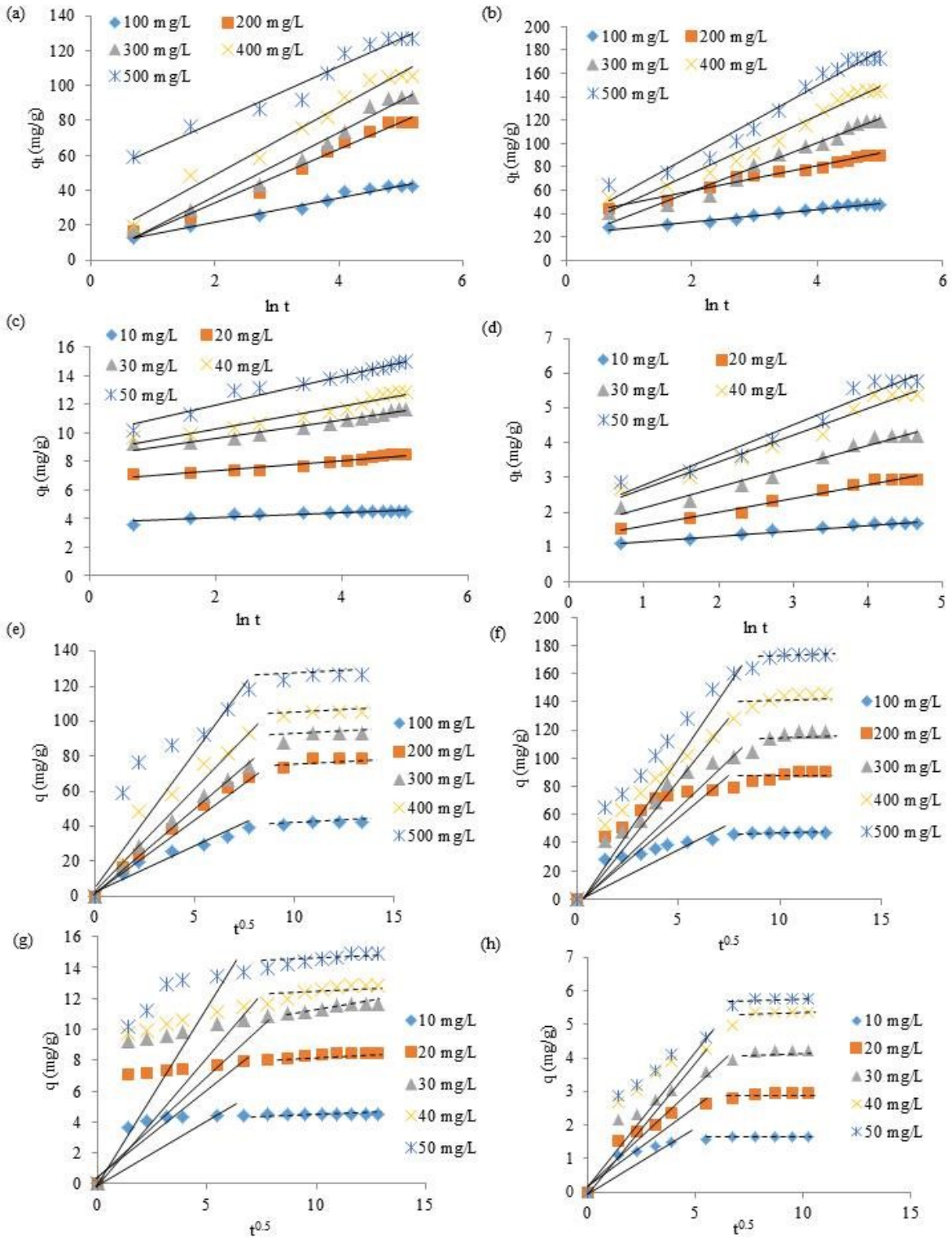

Figure S7. Elovich kinetics model for BBR adsorption on (a) AC 55, (b) AC 65; Zn adsorption on (c) AC 55, (d) AC 65. Intra particle kinetic model for BBR adsorption on (e) AC 55, (f) AC 65; for Zn adsorption on (g) AC 55, (h) AC 65. (pH 6, a contact time 120 minutes, agitation 180

rpm, a temperature of 30°C, and concentrations ranging from 100 to 500 mg/L for BBR and 10 to 50 mg/L for Zn ions)

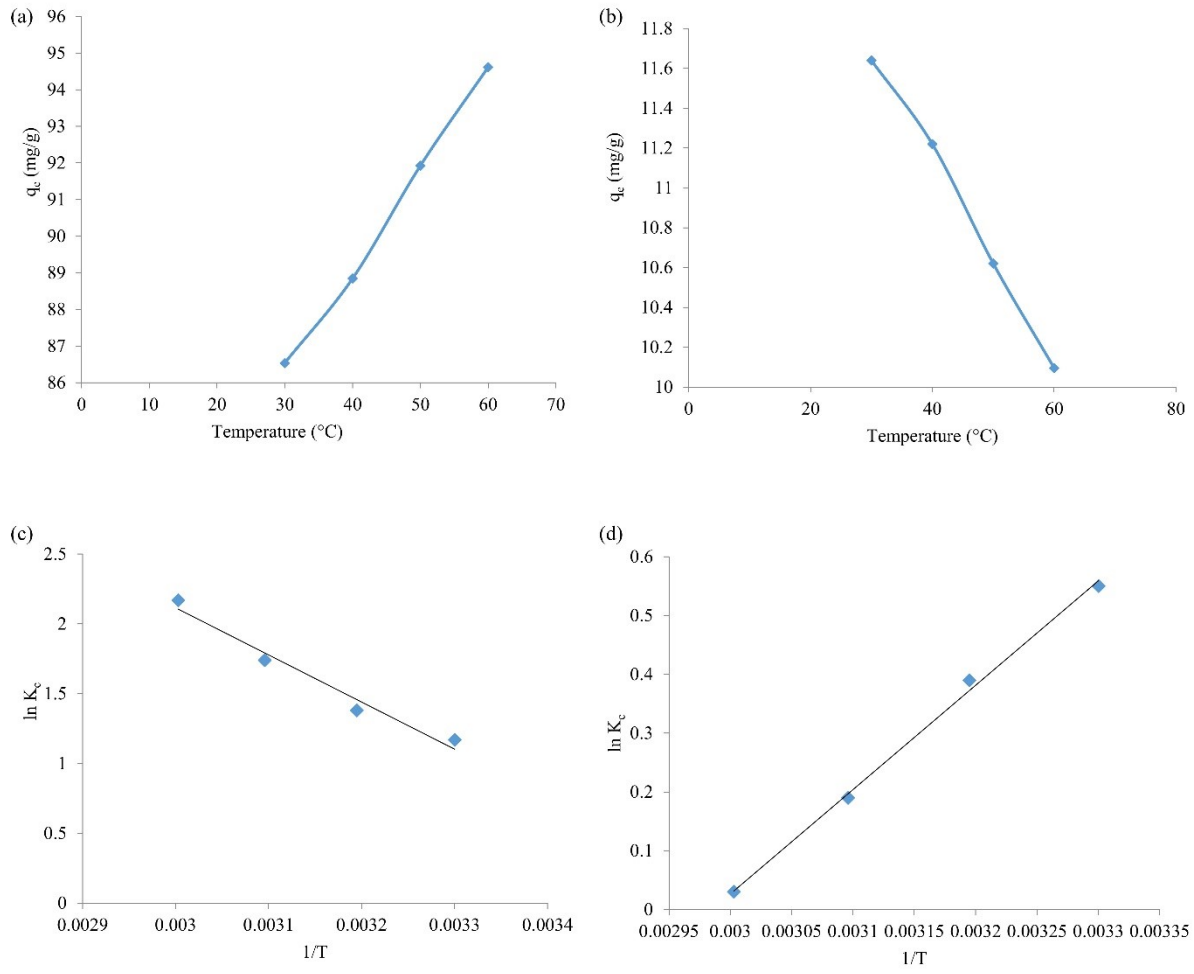

Figure S8. Effect of temperature on adsorption, (a) BBR dye on AC 65 (50 mL of 200 mg L^{-1} dye/0.1 g of AC) and (b) Zn on AC 55 (50 mL of 30 mg L^{-1} metal ion solution /0.1 g of AC); Van't Hoff plot for the adsorption of (c) BBR on AC 65 and (d) Zn on AC 55. (pH 6, a contact time 120 minutes, agitation 180 rpm, a temperature of 30°C).

Reference

1. Allahkarami E, Dehghan Monfared A, Silva LFO, Dotto GL. Lead ferrite-activated carbon magnetic composite for efficient removal of phenol from aqueous solutions: synthesis, characterization, and adsorption studies. *Sci Rep*. 2022;12(1):1-16. doi:10.1038/s41598-022-15077-x

2. Adam O. Removal of Resorcinol from Aqueous Solution by Activated Carbon: Isotherms, Thermodynamics and Kinetics. *Am Chem Sci J*. 2016;16(1):1-13. doi:10.9734/acsj/2016/27637