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ORIGINAL PAPER

# Magnetic and $K^+$-cross-linked *kappa*-carrageenan nanocomposite beads and adsorption of crystal violet

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**Abstract** Biopolymer-based magnetic beads, composed of *kappa*-carrageenan (κ-Car) and $Fe_3O_4$ nanoparticles, were synthesized. The magnetic beads were prepared through in situ precipitation of $Fe^{2+}$/$Fe^{3+}$ ions in the presence of carrageenan and subsequently treating with $K^+$ solution. The structure of magnetic *kappa*-carrageenan beads (mκ-Carb) was characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), vibrating sample magnetometer, and thermal gravimetric analysis techniques. According to SEM micrographs, an undulant and coarse structure with cubic-shaped sections was obtained when the magnetic nanoparticles were incorporated in composition of beads. The TEM image confirmed the formation of magnetic nanoparticles with an average size of 3–7 nm. The synthesized beads were examined as adsorbent to remove crystal violet dye from aqueous solutions. It was found that due to coarse surface, the rate of dye adsorption on magnetic beads can be improved slightly. The experimental adsorption kinetics was analyzed according to pseudo-first-order and pseudo-second-order kinetic models and the adsorption kinetics followed well the pseudo-second-order model. Isotherm adsorption data of dye on beads were modeled according to Langmuir and Freundlich isotherm models. The results revealed that the experimental data have the best fit to Langmuir isotherm model, and maximum adsorption capacity of beads for dye obtained was 84.7 mg/g. The influence of pH on the variation of adsorption capacity of beads for crystal violet was not considerable. The thermodynamic parameters indicated that the adsorption of CV dye on beads is spontaneous.

**Keywords** *kappa*-Carrageenan · Magnetic · Bead · Nanocomposite · Adsorption

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## Introduction

Carrageenan is a collective term for linear sulfated polysaccharides produced by alkaline extraction from red seaweed. The types of carrageenans differ only in the position and number of ester sulfate groups which determine their physicochemical properties, e.g., viscosity and gelation characteristics. Carrageenans comprise three main forms: *lambda* (non-gelling), *kappa* (strong gelling), and *iota* (weak gelling) [1]. Because of their exceptional properties, carrageenans are broadly used as ingredients in a variety of applications. They have several major characteristics that make them very useful in many food and non-food applications. They are used as cost-effective stabilizers, thermoreversible gelling agents, binders, thickeners, texture modifiers, and moisture retainers. There are numerous reviews of their chemistry [2] and applications in foods [3] and drug delivery systems [4].

The gelling of *kappa*-carrageenan can occur physically and chemically. *kappa*-Carrageenan contains anion sulfate pendant on its backbones. Electrostatic interactions between sulfate on carrageenan with metal cations (especially $K^+$) [5] and polycationic polyelectrolytes (especially chitosan) [6] are classes of physical cross-linking that have been used for synthesis of *kappa*-carrageenan hydrogels. Chitosan/carrageenan nanoparticles [6], alginate/