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Alginate $NiFe_2O_4$ Nanoparticles Cryogel for Electrochemical Glucose Biosensor Development

Amin Fatoni [1,*], Aziz Wijonarko [1], Mekar Dwi Anggraeni [2], Dadan Hermawan [1], Hartiwi Diastuti [1] and Zusfahair [1]

[1] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Jenderal Soedirman, Purwokerto 53122, Indonesia; wijonarkoaziz@gmail.com (A.W.); dadan.hermawan@unsoed.ac.id (D.H.); hartiwi.diastuti@unsoed.ac.id (H.D.); zusfahair@unsoed.ac.id (Z.)
[2] Department of Nursing, Faculty of Health Sciences, Universitas Jenderal Soedirman, Purwokerto 53122, Indonesia; mekar.anggraeni@unsoed.ac.id
* Correspondence: aminfatoni@unsoed.ac.id

Abstract: Glucose biosensors based on porous material of alginate cryogel has been developed, and the cryogel provides a large surface area for enzyme immobilization. The alginate cryogel has been supplemented with $NiFe_2O_4$ nanoparticles to improve the electron transfer for electrochemical detection. The fabrication parameters and operational conditions for the biosensor have also been optimized. The results showed that the optimum addition of $NiFe_2O_4$ nanoparticles to the alginate solution was 0.03 g/mL. The optimum operational conditions for the electrochemical detection were a cyclic voltammetry scan rate of 0.11 V/s, buffer pH of 7.0, and buffer concentration of 150 mM. The fabricated alginate $NiFe_2O_4$ nanoparticles cryogel-based glucose biosensor showed a linear response for glucose determination with a regression line of y = 18.18x + 455.28 and R^2 = 0.98. Furthermore, the calculated detection limit was 0.32 mM and the limit of quantification was 1.06 mM.

Keywords: alginate; cryogel; electrochemical; glucose biosensor; nickel ferrite nanoparticles

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1. Introduction

Diabetes mellitus is a degenerative disease that causes many deaths. About 43% of the 3.7 million deaths from diabetes mellitus occur before age of 70 years and the percentage of these deaths is higher in developing countries [1]. According to the International Diabetes Federation (IDF), in 2017, the prevalence of diabetes mellitus in the world reached 424.9 million people and is expected to reach 628.6 million in 2045 [2]. Diabetes mellitus is also found as the most comorbidities among individuals died due to COVID-19, especially in Central Java Province, Indonesia, with 39.7% and followed by hypertension at 31.6% (Central Java 2020).

There are preventive measures in place to reduce the number of people with diabetes mellitus. Previous strategies reported for early detection were to determine blood glucose levels with a biosensor [3]. In general, the glucose biosensor uses the enzyme glucose oxidase to catalyze the glucose conversion and the results could be detected electrochemically. The combination of biological sensing elements such as an enzyme and a transducer such as an electrochemical transducer is the main principle of the biosensor for analyte determination [4]. Biosensors have shown several advantages such as being easy to manufacture in small tools (portable), relatively inexpensive, high sensitivity, high selectivity, and making real-time measurements possible. As a result, they have been widely developed and commercialized as analytical tools [5].

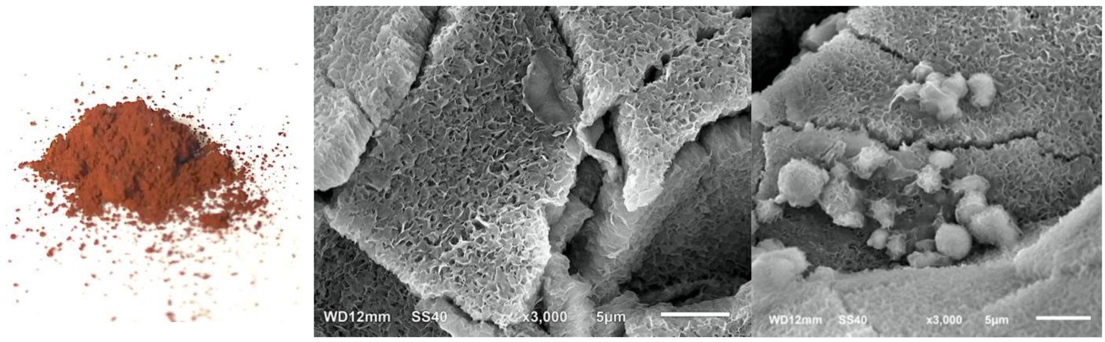
The development of biosensors is generally focused on increasing their sensitivity, selectivity, stability, or reducing their production costs. The development strategies could be performed in the biological compound exploration of biological sensing elements such as enzymes, antibodies, cells, supporting materials for biological compound immobilization or the detector improvisation. In developing an enzyme supporting material, a previous study showed that the use of chitosan cryogel increases the surface area of the electrode, thereby increasing the performance of electrochemical biosensors [6]. However, the non-conductive nature of chitosan reduces the electric current when it has been applied with an electrochemical transducer. Various strategies to improve the chitosan conductivity have been explored, such as using carbon nanotubes [7] and grafting with polyaniline [8]. However, it is still challenging to find better enzyme support materials for detecting glucose. Besides chitosan, another biopolymer showed an excellent property as porous supporting material is alginate. Alginate is hydrophilic, biocompatible and biodegradable [9]. Alginate has been used in tissue engineering [10], drug delivery [11], enzyme immobilization [12], and biosensors [13]. Furthermore, the calcium alginate matric for enzyme immobilization could be easily prepared using a simple procedure compared to crosslinking of chitosan. The use of crosslinker agent such as glutaraldehyde is not environmentally friendly, and it could be cytotoxic in case of the biological sensing element using bacteria cell. The green technology using urea-induced gelation for chitosan crosslinking was a relatively complex procedure and resulted in non-stable gel compared to glutaraldehyde crosslinked [14]. Another advantage of alginate matric compared to chitosan is that it has a greater capacity for biomolecule entrapment [15].

Despite the numerous advantages, the use of biomaterial such as chitosan and alginate in the application of biosensors with electrochemical detection has poor mechanical and electrical properties. It has been reported that composites made from biomaterials and nanoparticles overcome these poor electrical properties [7,16]. This research used nickel ferrite nanoparticles to improve the alginate cryogel for glucose biosensor application using electrochemical detection.

2. Results and Discussion

2.1. $NiFe_2O_4$ Nanoparticles Preparation and Characterization

The $NiFe_2O_4$ nanoparticles were synthesized to improve the performance of the alginate cryogel modified electrode. The $NiFe_2O_4$ nanoparticles were prepared using co-precipitation which was a bottom-up synthesis of nanoparticle from their metal ions to obtain nanosized particles. The co-precipitation method was selected because of its simplicity and ease of obtaining the homogenous size [17,18]. The obtained $NiFe_2O_4$ nanoparticles were a brown powder (Figure 1A). The $NiFe_2O_4$ nanoparticles prepared using the same procedure have been reported to have a particle size of 4.2–5.7 nm observed by transmission electron microscopy and magnetic coercivity of 42–47 Oe [19].



A B C

Figure 1. Synthesized $NiFe_2O_4$ nanoparticles showed as a dark brown powder (**A**). The porous structure of cryogel is made of alginate (**B**) and alginate with $NiFe_2O_4$ nanoparticles (**C**).

Alginate cryogel was formed by crosslinking sodium alginate under subzero temperature to freeze the water solvent and leave a porous structure [7]. The $NiFe_2O_4$ nanoparticles were entrapped in the alginate structure to facilitate the electron transfer during the redox reaction of the working electrode. The scanning electron microscope image showed that the porous alginate cryogel had a large surface area (Figure 1B,C) with a pore size of about 1–2 micron pores. Subsequently, the alginate $NiFe_2O_4$ nanoparticles cryogel structure and alginate only cryogel showed a similar porous material with an aggregate of $NiFe_2O_4$ nanoparticles on the surface of the alginate $NiFe_2O_4$ nanoparticles cryogel.

2.2. *Alginate $NiFe_2O_4$ Nanoparticles Modified Electrode Performance*

The performance of the alginate-$NiFe_2O_4$ nanoparticles cryogel electrode was tested using potassium hexacyanoferrate and hydrogen peroxide. Potassium hexacyanoferrate was used to observe the electron transfer behavior of each step of electrode modification. The results showed that the glassy carbon electrode with alginate cryogel (Figure 2A, red) had lower oxidation and reduction peaks compared to a bare glassy carbon electrode (Figure 2A, red). The lower oxidation and reduction peaks of alginate cryogel were due to the low conductivity characteristic of alginate [20]. Therefore, strategies to improve the alginate conductivity of the alginate are required. The alginate $NiFe_2O_4$ nanoparticles cryogel showed higher oxidation and reduction peaks (Figure 2A, green), compared to both bar glassy carbon electrode and alginate cryogel modified electrode. The higher oxidation and reduction peaks of the $NiFe_2O_4$ nanoparticles alginate cryogel due to the large surface area of porous cryogel combined with the nickel ferrite nanoparticles.

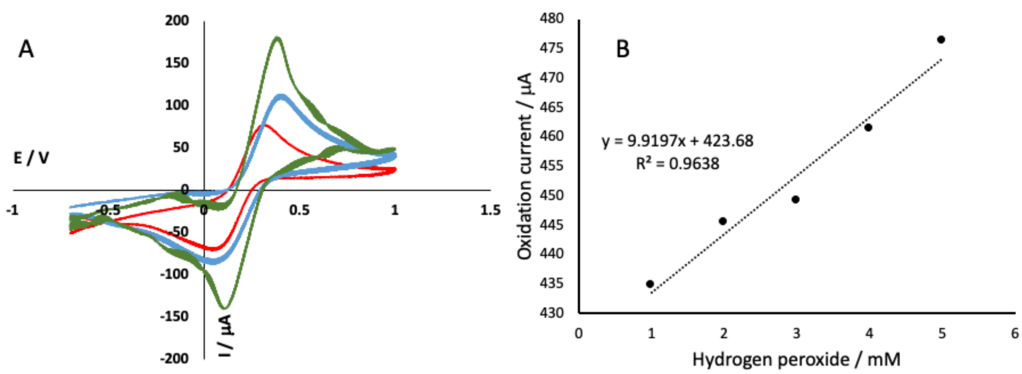


Figure 2. Electron transfer behavior of a bare glassy carbon electrode (**A**, blue line), alginate cryogel modified electrode (**A**, red line), and alginate-$NiFe_2O_4$ nanoparticles cryogel modified electrode (**A**, green line) measured on 10 mM potassium ferricyanide. Alginate-$NiFe_2O_4$ nanoparticles modified electrode showed a linear response for detecting hydrogen peroxide (**B**).

It was previously reported that nickel ferrite nanoparticles increase the conductivity of the compound with PANI [21], polypyrrole-chitosan [22] and alginic acid [23]. Besides improving the electron transfer of the alginate cryogel by adding $NiFe_2O_4$ nanoparticles, this nanoparticle with the magnetic properties also makes the alginate cryogel became magnetic alginate cryogel. The magnetic alginate based gels have been reported in many fields such as biosensors [24], drug delivery [25] and tissue engineering [26]. The magnetic materials embedded in the gels provide unique features such as responding to the applied magnetic fields, inducing shape changes and modifying the mechanical properties [27]. The nanoparticle of $NiFe_2O_4$ provides magnetism of small size ferromagnetic (superparamagnetism) showed unique properties that could enhance the biosensor sensitivity and allow rapid detection of various analytes [28]. Therefore, the increase of the redox peaks observed in this research can also be caused by the super magnetism of nanoparticles added to the alginate gels.

Hydrogen peroxide was first used to simulate the glucose biosensor, since the use of glucose oxidase enzyme would result in hydrogen peroxide which was eventually detected by electrochemical detection. The electrochemical method used was cyclic voltammetry, which is a cyclic method that describes the movement of electrons due to a reduction and oxidation reaction occurring on the surface of the working electrode. The results showed a linear response of hydrogen peroxide determination (1–5 mM, in phosphate buffer) using alginate-$NiFe_2O_4$ nanoparticles modified electrode performed using cyclic voltammetry (Figure 2B).

2.3. $NiFe_2O_4$ Nanoparticles Addition Optimization

$NiFe_2O_4$ nanoparticles were added to the alginate cryogel to improve the electron transfer properties. However, the addition of nanomaterials could be increasing the cost in further application. Therefore, finding the best condition with the lowest number of nanoparticles addition was important but showed the optimal electron transfer properties.

The $NiFe_2O_4$ nanoparticles was added in various final concentration of 0.01, 0.02, 0.03, 0.04 and 0.05 g/mL of sodium alginate solution. The result showed the increase of oxidation current with the addition of $NiFe_2O_4$ nanoparticles from 0.01 to 0.03 g/mL. However, the higher amount of the nanoparticles did not show a significant oxidation current change (Figure 3). The nanoparticle composite in alginate polymers was generally prepared in the composition of 0–10% (*w*/*v*) such as in the alginate-magnetic nanoparticles [29], alginate silver nanoparticles [30], alginate-Fe_3O_4 nanoparticles [31] and alginate multi-walled carbon nanotubes [32].

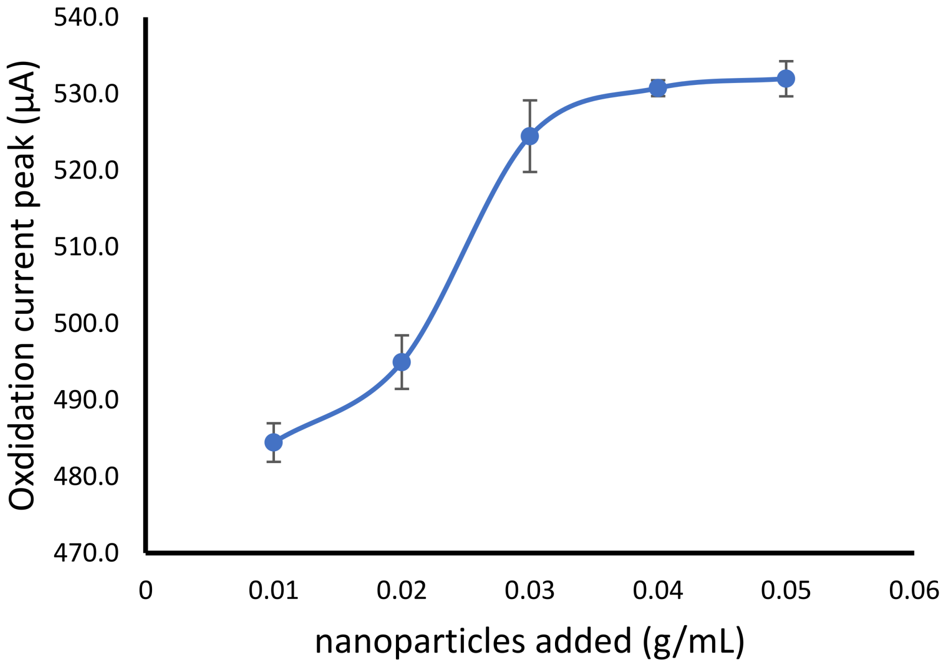


Figure 3. Effect of $NiFe_2O_4$ nanoparticles addition to alginate cryogel on the increase of oxidation peak of hydrogen peroxide.

2.4. Effect of Cyclic Voltammetry Scan Rate

The CV method for the determination of hydrogen peroxide using modified alginate $NiFe_2O_4$ nanoparticles has been studied the effect of scan rate using phosphate buffer pH 7.0 with a concentration of 100 mM. The scan rate range used was 0.05–0.13 V/s. The increase in the scan rate causes the increase of electron transfer per second, leading to the accumulation of electrolyte ions. Therefore, each increase in the scan rate would increase the oxidation peak current, making it difficult to obtain the optimum condition of the scan rate, similar to the previous report [33]. However, an increase in scan rate with the increase in the oxidation peak current from 0.06 to 0.11 V/s showed a higher current increase, while the higher scan rate of more than 0.11 V/s showed a lower increase in the oxidation peak current (Figure 4).

2.5. Effect of Buffer pH and Concentration on the Detection of Hydrogen Peroxide

The buffer pH was optimized using 0.1 M phosphate buffer with various pH of 6.0, 6.5, 7.0, 7.5 and 8.0. The result showed that the optimum pH for the determination of hydrogen peroxide was at a pH of 7.0 (Figure 5). The increase of buffer pH from 6.0 to 7.0 showed an increase of oxidation current peak. However, the higher pH of more than 7.0 did not significantly increase in the current oxidation peak. The pH of 7.0 was also selected based on the glucose oxidase enzyme having an optimum pH of 7.0 when applied as glucose biosensor [7]. In some cases, the change of pH can lead to a change in oxidation or reduction peak [34], which may be favorable to improve the selectivity. In this study, various pH showed similar oxidation peak potential but different their peak height.

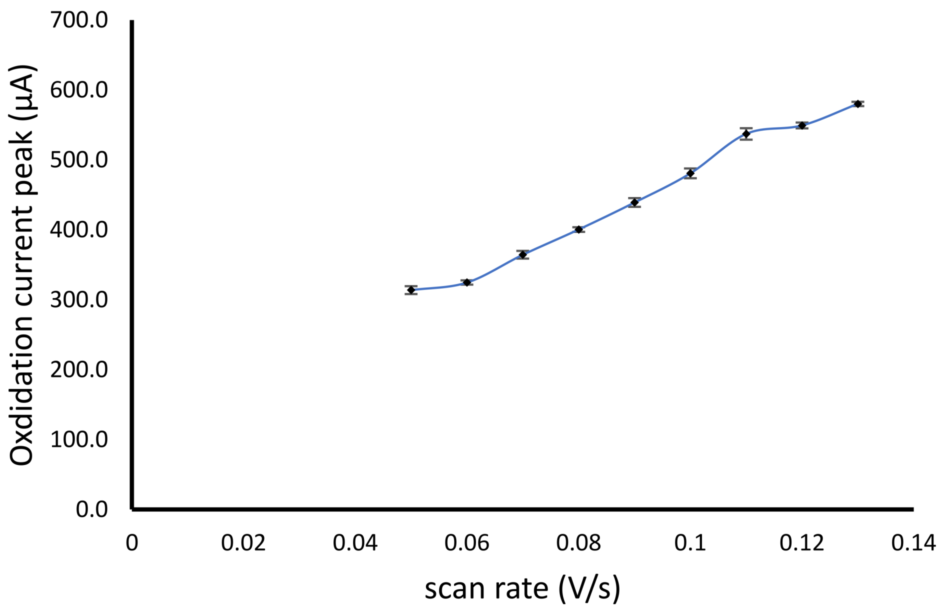


Figure 4. Scan rate optimization of the cyclic voltammetry method for hydrogen peroxide determination using modified alginate $NiFe_2O_4$ nanoparticles cryogel electrode.

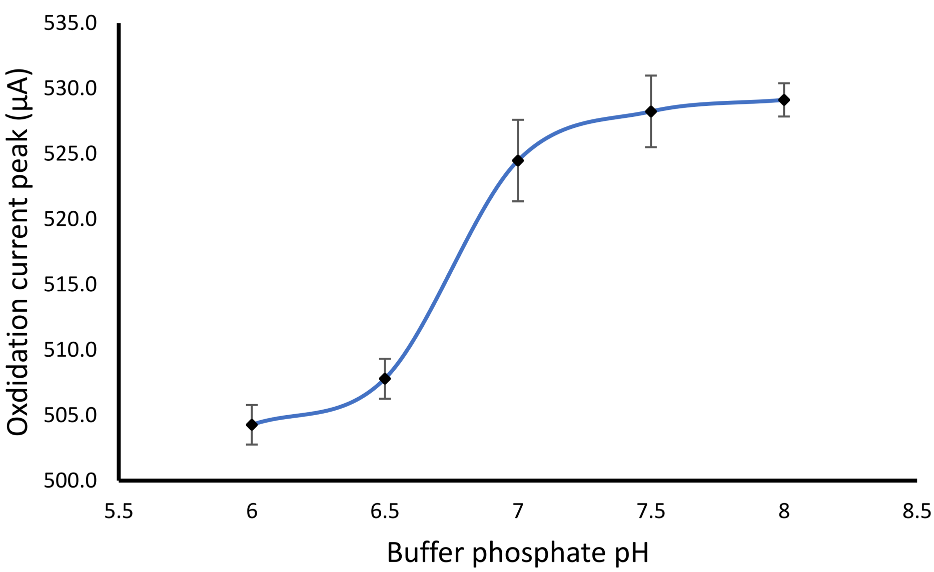


Figure 5. Effect of buffer pH on the hydrogen peroxide oxidation peak using the modified alginate-$NiFe_2O_4$ nanoparticles cryogel electrode.

The concentration of the phosphate buffer influences the redox behavior of hydrogen peroxide, since the electron transfer highly depends on the electrolyte concentration in the medium. The result showed an increase in the buffer concentration from 50 to 150 mM, while the higher buffer concentration did not show a significant increase (Figure 6). The buffer concentration of the buffer was an important factor affecting the sensitivity of the biosensor. The concentration of the buffer causes a change in the capacity of the ionic form of the substance in the solution. The higher the buffer concentration, the more free ions from the buffer salt contained in the solution, thus increasing the current value. Optimal buffer concentration could provide a high sensitivity of the biosensor.

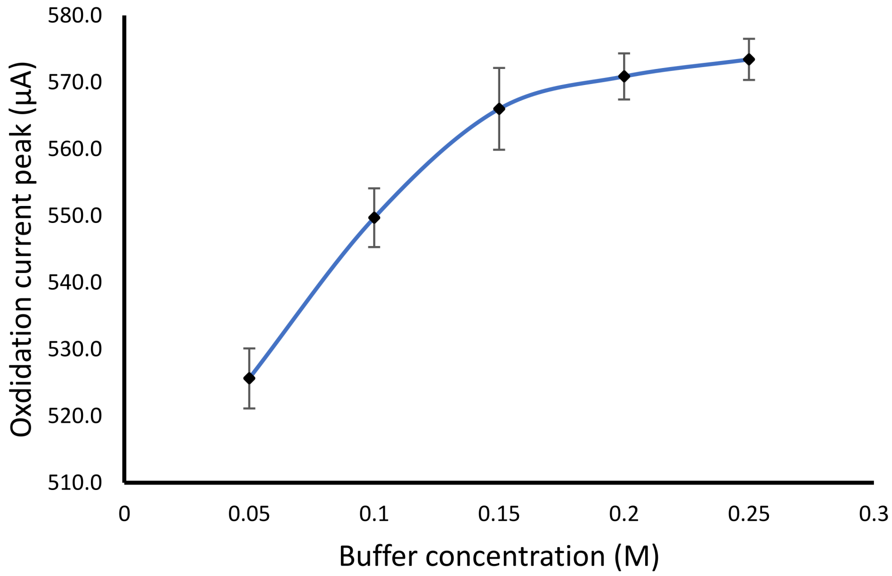


Figure 6. Buffer concentration effect on the hydrogen peroxide determination using the modified electrode.

2.6. Glucose Determination Using Fabricated Biosensor

The glucose determination was performed with the glucose oxidase enzyme entrapped in the alginate $NiFe_2O_4$ nanoparticles cryogel. The electrochemical measurement was based on the determination hydrogen peroxide which results from the enzymatic reaction of glucose catalyzed by glucose oxidase in the following redox reaction:

$$Glucose + O_2 \xrightarrow{glucose\ oxidase} H_2O_2 + gluconic\ acid \quad (1)$$

$$H_2O_2 \xrightarrow{modified\ electrode} O_2 + 2\ H^+ + 2\ e^- \quad (ox) \quad (2)$$

$$H_2O_2 + 2\ H^+ + 2\ e^- \xrightarrow{modified\ electrode} 2H_2O \quad (red) \quad (3)$$

The result showed that the peaks current was increased linearly with the glucose concentration with the regression equation of y = 16.18x + 455.28 and R^2 of 0.981 (Figure 7). The calculated limit of detection and limit of quantification were 0.32 mM and 1.06 mM respectively. The fabricated electrochemical alginate-$NiFe_2O_4$ nanoparticles cryogel based glucose biosensor was more sensitive compared to colorimetric alginate-based glucose biosensor [13] and near-infrared alginate-based glucose biosensor [35].

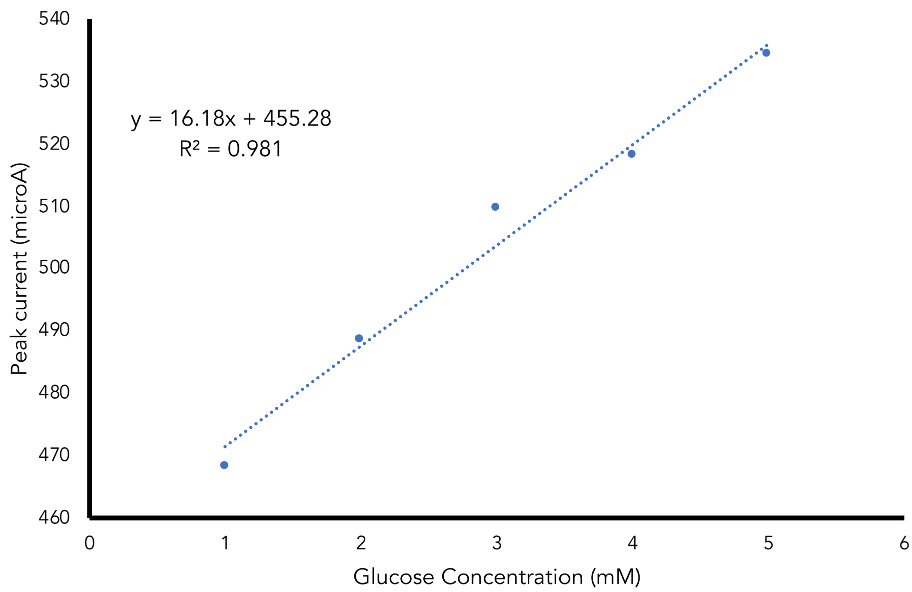


Figure 7. Glucose determination using fabricated alginate $NiFe_2O_4$ nanoparticles cryogel biosensor.

3. Conclusions

Alginate $NiFe_2O_4$ nanoparticles composite as supporting material in the fabricated glucose biosensor showed a high surface area and good electron transfer using an electrochemical detector. The optimal conditions obtained were the addition of $NiFe_2O_4$ nanoparticles of 0.03 g/mL sodium alginate solution, a scan rate of 0.11 V/s, phosphate buffer pH of 7.0 and buffer concentration of 150 mM. The determination of the glucose using immobilized GOD enzyme showed a linear response with regression equation of y = 16.18x + 455.28 and R^2 of 0.98. The limit of detection obtained was 0.32 and the limit of quantification was 1.06 mM.

4. Materials and Methods

4.1. Materials

Alginic acid sodium salt from brown algae (BioReagent, Sigma-Aldrich, St. Louis, MI, USA), glucose oxidase from *Aspergillus niger* (type II, ≥15,000 U/g solid, Sigma-Aldrich, St. Louis, MI, USA), nickel(II) chloride ($NiCl_2 \cdot 6H_2O$) Merck KGaA, Darmstadt, Germany), iron(III) chloride ($FeCl_3 \cdot 6H_2O$) (Merck KGaA, Darmstadt, Germany), glucose anhydrous (≥98.0%) (Sigma), acetic acid (CH_3COOH) (Merck KGaA, Darmstadt, Germany), hydrogen peroxide (H_2O_2) 30% (Merck KGaA, Darmstadt, Germany), sodium hydroxide (NaOH) (Merck KGaA, Darmstadt, Germany), disodium hydrogen phosphate (Merck KGaA, Darmstadt, Germany) and sodium dihydrogen phosphate (Merck KGaA, Darmstadt, Germany).

4.2. Apparatus and Measurements

Scanning electron microscopy (SEM) (JSM-6510 LA, JEOL, Tokyo, Japan), operating at 15 kV, was used to examine the morphology of the alginate nanoparticle cryogel. The electrochemical analysis was performed using a three-electrode system with a glassy carbon electrode as a working electrode and Ag/AgCl as a reference electrode and platinum wire as a counter electrode. The electrochemical measurements were carried out using Rodeostat Potentiostat (IORodeo Smart Lab Technology, Pasadena, CA, USA).

4.3. $NiFe_2O_4$ Nanoparticles Preparation

Nickel ferrite nanoparticles have been synthesized using the co-precipitation method [36] with $NiCl_2 \cdot 6H_2O$ and $FeCl_3 \cdot 6H_2O$ as ion providers Ni^{2+} and Fe^{3+}. The mole fraction ratio used was 1:2, by dissolving 1.188 g of $NiCl_2 \cdot 6H_2O$ in 20 mL distilled water and 2701 g of $FeCl_3 \cdot 6H_2O$ in 20 mL of distilled water in a separate glass beaker. The two solutions were then mixed homogeneously. The mixture of Ni and Fe was then dropwise slowly in the precipitation agent of NaOH under stirring (1000 rpm) at 85 °C for 60 min. The variation of NaOH concentrations used were 3, 5, 7, 9 and 11 M. The resulting nanoparticles were then precipitated continued by washing distilled water for approximately seven times of 50 mL. The precipitated nanoparticles obtained were dried at 90 °C. The brown nanoparticles powder was then used for further procedures.

4.4. Alginate Cryogel Electrode Preparation

Sodium alginate solution was prepared by dissolving 2.0 g of alginate in phosphate buffer (100 mM, pH 7) to get 100 mL of solution. The 50 µL of alginate solution was then drop on the glassy carbon working electrode (3 mm diameter). The electrode with alginate cover was immerse in 2 M $CaCl_2$ solution and allowed for 30 min to make the crosslink layer of Ca-alginate on the electrode. The electrode was then kept in the freezer at −20 °C for 12 h to continue the crosslinking reaction with the freezing condition for cryogel forming.

Alginate $NiFe_2O_4$ nanoparticles were prepared using similar procedure above with the addition of $NiFe_2O_4$ to the alginate solution with the concentration of 0.1, 0.2, 0.3, 0.4 and 0.5 g per 100 mL alginate solution. The mixture was then dropped in on the glassy carbon electrode and further the procedure of alginate cryogel modified electrode. The modified electrode with alginate cryogel and alginate $NiFe_2O_4$ has been tested using $K_3[Fe(CN)_6]$ and H_2O_2 (in 100mM phosphate buffer, pH of 7.0) solution by cyclic voltammetry method.

4.5. Cyclic Voltammetry Optimization

The optimal condition of the electrochemical cell using cyclic voltammetry (−1.0 to 1.0 V, 3 scans) were performed by variating the scan rate of 0.05, 0.06, 0.07, 0.08, 0.09, 0.10, 0.11, 0.12 and 0.13 mV/s. The solution used was H_2O_2 5 mM in phosphate buffer pH 7.0. The best scan rate with the minimum background current was then selected for further study.

4.6. Buffer pH and Concentration Optimization

The buffer pH and concentration were optimized in the H_2O_2 determination with a variation of pH 6.0 to 8.0 with the various concentrations of 50, 100, 150, 200 and 250 mM. The cyclic voltammetry conditions included the optimized parameters obtained.

4.7. Glucose Determination Using Modified Electrode

Glucose oxidase as biological sensing element was prepared in buffer solution (pH 7.0, concentration 50 mM). The enzyme was immobilized in the working electrode by entrapping method. The glucose oxidase solution was then added to the alginate solution (20 µL/1000 µL) with the total enzyme activity of 50 U per modified electrode made of 50 µL solution of alginate-$NiFe_2O_4$ nanoparticles. The mixture was then dropped on the working electrode surface, dipped in the crosslinking agent and kept in the freezer for cryogelation. The modified electrode was then tested to detect glucose standard solution under the optimal condition. Linearity, the limit of detection and limit of quantification were then calculated from the series concentration of glucose determined.

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Conflicts of Interest: The authors declare no conflict of interest.

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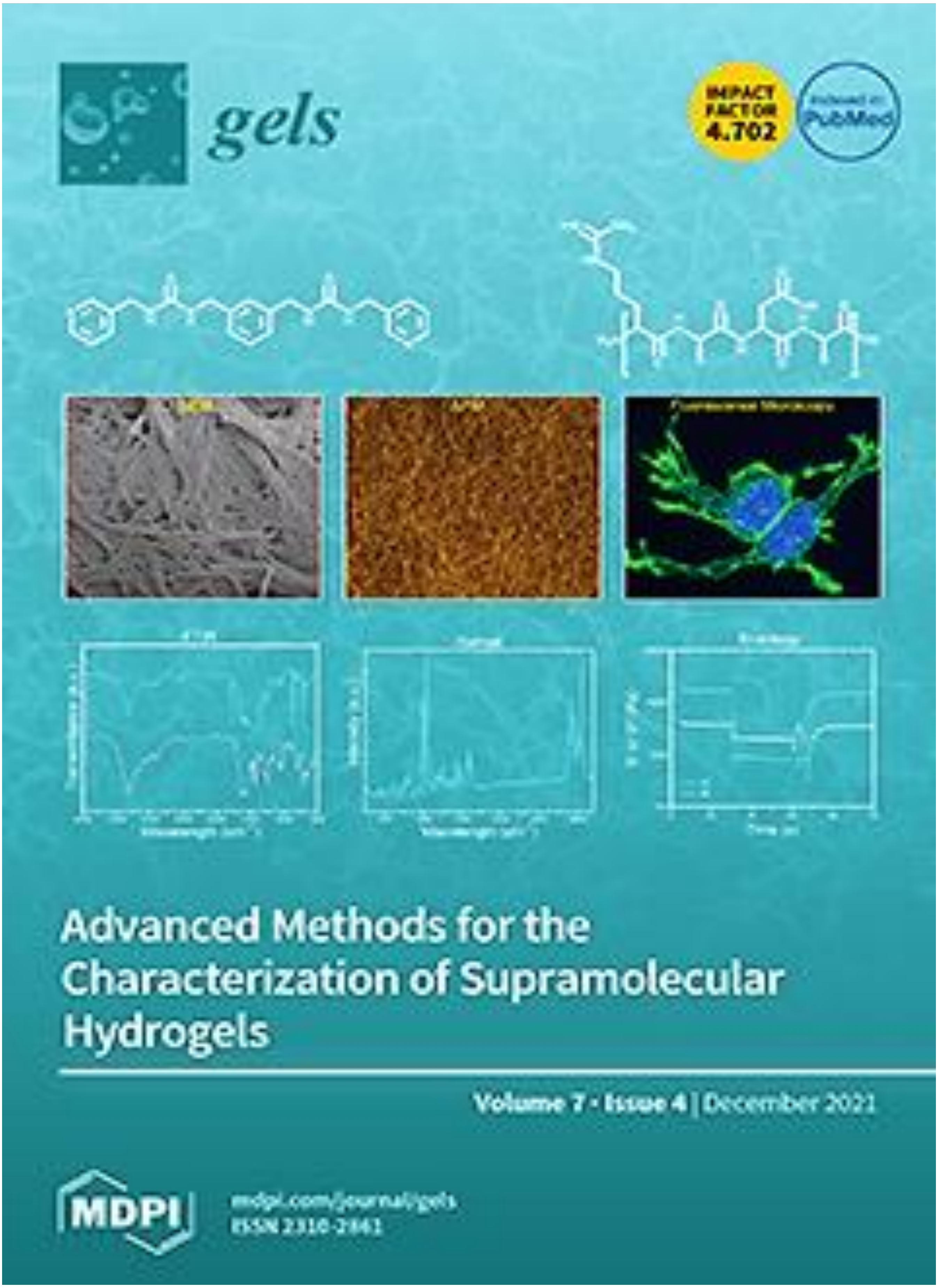
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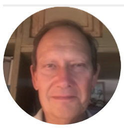

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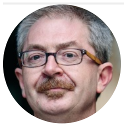

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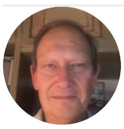

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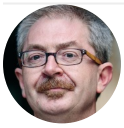

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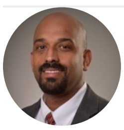

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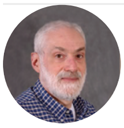

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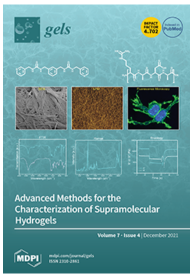

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Novel Thermosensitive-*co*-Zwitterionic Sulfobetaine Gels for Metal Ion Removal: Synthesis and Characterization (/2310-2861/7/4/273)

by Eva Oktavia Ningrum (https://sciprofiles.com/profile/1344596), Takehiko Gotoh (https://sciprofiles.com/profile/1061559), Wirawan Ciptonugroho (https://sciprofiles.com/profile/author/VkZlSFBUcjNWMnd0bm9vbTEwaGxJWEZFb3diSGtWT2FqS1Qyb3NKa3pRUlRjS ,

Achmad Dwitama Karisma (https://sciprofiles.com/profile/author/SXJ2ZHQ5cWN3RGlzcE9Ta2d0VzBDR3dkUm50MTVlY1V0elJOT1FNZmxLYz0
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Elly Agustiani (https://sciprofiles.com/profile/author/VWkrYU1hUURXMWtmcng0MWZhU0tndy9wYXEzc1p5OUVYN01UNGlJdTdBWT0=),
Zela Marni Safitri (https://sciprofiles.com/profile/author/NE1wR2JPNkZrQUlyOHZ0Z3k2U1c3NXFEeHp... and
Muhammad Asyam Dzaky (https://sciprofiles.com/profile/author/ODgzcStWQnpaS1VEV3dlT1JvYlp5M095SUk1djEwOHE5eWxEZjV0YkFXWT0=
Gels **2021**, *7*(4), 273; **https://doi.org/10.3390/gels7040273 (https://doi.org/10.3390/gels7040273)** - 17 Dec 2021
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Abstract Zwitterionic betaine polymers are promising adsorbents for the removal of heavy metal ions from industrial effluents. Although the presence of both negative and positively charged groups imparts them the ability to simultaneously remove cations and anions, intra- and/or inter-chain interactions can significantly reduce **[...] Read more.**
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Alginate $NiFe_2O_4$ Nanoparticles Cryogel for Electrochemical Glucose Biosensor Development (/2310-2861/7/4/272)

by Amin Fatoni (https://sciprofiles.com/profile/850176),
Aziz Wijonarko (https://sciprofiles.com/profile/author/Sjhad0hhNVZ6ZGtBMFZaa3U1M2Z0bVo0dnZRRXlIdEdJbStGWXV3dnhFYz0=),
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Gels **2021**, *7*(4), 272; **https://doi.org/10.3390/gels7040272 (https://doi.org/10.3390/gels7040272)** - 17 Dec 2021
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Abstract Glucose biosensors based on porous material of alginate cryogel has been developed, and the cryogel provides a large surface area for enzyme immobilization. The alginate cryogel has been supplemented with $NiFe_2O_4$ nanoparticles to improve the electron transfer for electrochemical detection. **[...] Read more.**
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Open Access Article (/2310-2861/7/4/271/pdf?version=1639726816)

Role of Sodium Dodecyl Sulfate in Tailoring the Rheological Properties of High-Strength Gelatin Hydrogels (/2310-2861/7/4/271)

by Virginia Martin Torrejon (https://sciprofiles.com/profile/1374088), Yanqiu Deng (https://sciprofiles.com/profile/1972447),
Guidong Luo (https://sciprofiles.com/profile/author/bTJUWHFyYU5NLzVxb3lNelVDQUdKV2pRYys2WTN3RUpZL3N6MmVFYlhVcz0=),
Bingjie Wu (https://sciprofiles.com/profile/1966637), Jim Song (https://sciprofiles.com/profile/1948786),
Song Hang (https://sciprofiles.com/profile/author/ZmxqNitBbEt4dDlmVWZHeU1qY0JmYXNHVlhWaHJUeVR3WVJTZXExVW03ST0=) and
Dongmei Wang (https://sciprofiles.com/profile/1376250)
Gels **2021**, *7*(4), 271; **https://doi.org/10.3390/gels7040271 (https://doi.org/10.3390/gels7040271)** - 16 Dec 2021
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Abstract Gelatin hydrogels are widely used materials that may require surfactants to adjust their solution's surface tension for cell attachment, surface adsorption enhancement, or foaming. However, gelatin is a highly surface-active polymer, and its concentrated solutions usually do not require surfactants to achieve low **[...] Read more.**

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Open Access Article (/2310-2861/7/4/270/pdf?version=1639665066)

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[Potential Usage of Hybrid Polymers Binders Based on Fly Ash with the Addition of PVA with Satisfying Mechanical and Radiological Properties (/2310-2861/7/4/270)]

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by Miljana Mirković (https://sciprofiles.com/profile/960085), Ljiljana Kljajević (https://sciprofiles.com/profile/author/UFBUY2hhUUlDV0xVamEwTUJoUTB1cWdmRGxCc2E5VFNVVkl1N3FvVTZhYz0=), Sabina Dolenec (https://sciprofiles.com/profile/174077), Miloš Nenadović (https://sciprofiles.com/profile/author/NTZ6SzltbmMwS2RDQm80RVpJZ1Q3Zz09), Vladimir Pavlović (https://sciprofiles.com/profile/2082030), Milica Rajačić (https://sciprofiles.com/profile/1955264) and Snežana Nenadović (https://sciprofiles.com/profile/958470)

Gels **2021**, *7*(4), 270; https://doi.org/10.3390/gels7040270 (https://doi.org/10.3390/gels7040270) - 16 Dec 2021

Abstract Since recycled technologies usage is mandatory for environmental safety, and in this regard, it is important to examine new materials that can be used in construction and are primarily produced from fly ash. In addition to characteristics such as hardness and compressive strength, [...] Read more.

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Open Access Article (/2310-2861/7/4/269/pdf?version=1641378966)

[Sol–Gel Co-Precipitation Synthesis, Anticoagulant and Anti-Platelet Activities of Copper-Doped Nickel Manganite Nanoparticles (/2310-2861/7/4/269)]

by Shashidharagowda H. (https://sciprofiles.com/profile/author/OXFzWmlEQmU4OEQzTTRpZUtrSE0zT1Ztb2ZheWZDb3NGcEhGeGdLT1c4bz0=), Shridhar Mathad (https://sciprofiles.com/profile/1886930), Shridhar Malladi (https://sciprofiles.com/profile/author/UlkwaTJqRDlwRXlxZ2JHRE1COGhZZVZtM0J0SkNwdzhYbmNiN3BTby9vcz0=), Vinod Gubbiveeranna (https://sciprofiles.com/profile/author/ZW0zd0d5bENBZytWRC9rcWNXL0MvczJySXlMZDN4cS9hdWl2Y0g5RDlHaz0=), Kusuma C. G. (https://sciprofiles.com/profile/author/d0Q4bml4bWFtdzBoMWZ4Y05wVUw4Y0lWdUdrTHFlWnVlQWFidVoyaDlFOD0=), Nagaraju S. (https://sciprofiles.com/profile/author/Tjk4L3ZBRy9wNEt6UlFqYlV2UjRtWlFTbjZ0VEpRakhFQXBxL1JTY2RNaz0=), Arun Y. Patil (https://sciprofiles.com/profile/1261842), Anish Khan (https://sciprofiles.com/profile/1300380), Malik Abdul Rub (https://sciprofiles.com/profile/1504149), Abdullah M. Asiri (https://sciprofiles.com/profile/3375) and Naved Azum (https://sciprofiles.com/profile/587049)

Gels **2021**, *7*(4), 269; https://doi.org/10.3390/gels7040269 (https://doi.org/10.3390/gels7040269) - 16 Dec 2021

Abstract Copper-substituted nickel manganites $Ni_{(1-x)}Cu_xMn_2O_4$ (Ni-TCE-NPs) were produced by co-precipitation route (sol–gel) at room temperature. $Ni_{(1-x)}CuxMn_2O_4$-Bio (NCB) NPs were studied by powder X-ray diffraction technique, scanning electron microscopy and Raman spectroscopy. [...] Read more.

(This article belongs to the Special Issue **Nanocomposite Hydrogels for Advanced Applications (/journal/gels/special_issues/nanocomposite_hydrogels_for_advanced_applications)**)

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Open Access Article (/2310-2861/7/4/268/pdf?version=1639651301)

[In Situ Pinpoint Photopolymerization of Phos-Tag Polyacrylamide Gel in Poly(dimethylsiloxane)/Glass Microchip for Specific Entrapment, Derivatization, and Separation of Phosphorylated Compounds (/2310-2861/7/4/268)]

by Sachio Yamamoto (https://sciprofiles.com/profile/1854560), Shoko Yano (https://sciprofiles.com/profile/author/ZmM1Wk9WU3FPN2xTZ2xEZCtyd0dnRHVDWUtNNDloRlZzU3owaVRsM3dXQT0=), Mitsuhiro Kinoshita (https://sciprofiles.com/profile/1931559) and Shigeo Suzuki (https://sciprofiles.com/profile/106972)

Gels **2021**, *7*(4), 268; https://doi.org/10.3390/gels7040268 (https://doi.org/10.3390/gels7040268) - 16 Dec 2021

Abstract An improved method for the online preconcentration, derivatization, and separation of phosphorylated compounds was developed based on the affinity of a Phos-tag acrylamide gel formed at the intersection of a polydimethylsiloxane/glass multichannel microfluidic chip toward these compounds. The acrylamide solution comprised Phos-tag acrylamide, [...] Read more.

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[Chia Seeds (*Salvia hispanica* L.): Can They Be Used as Ingredients in Making Sports Energy Gel? (/2310-2861/7/4/267)]

by Yanesti Nuravianda Lestari (https://sciprofiles.com/profile/1876599), Eko Farida (https://sciprofiles.com/profile/author/WHQvdERsRnVnaCtmdXlyNEVwUDB0ZlU4Tm12WkJCTUpuVjNzVWZ2OTJ6RT0=), Nur Amin (https://sciprofiles.com/profile/author/Y0hVYkUvQXNtb2FFQUd3KzA0SDRYTEY3QWNSYVlPaDV5bk9wRXRBbFkwZz0=), Wiwik Afridah (https://sciprofiles.com/profile/author/VlM1Y004OHVGakFiYlRVMmRodlRUTEt0NG5YMVlBMVNMVVpJZXpHSlFlUT0=), Fifi Khoirul Fitriyah (https://sciprofiles.com/profile/author/SGg5VDF5UHppcVFHZTNhMVhVUWtPdi9lNWJRVURxNDlMTTQybEttUG43OD0=) and Sunanto Sunanto (https://sciprofiles.com/profile/author/b0J0bFYwVjEyZTFFT0NWd1dHcE0ybVZWaWZrS1lzWmlZWmVsMU5WOXUrND0=)

Gels **2021**, *7*(4), 267; https://doi.org/10.3390/gels7040267 (https://doi.org/10.3390/gels7040267) - 16 Dec 2021

Abstract Dehydration during exercise has been shown to limit performance. This study aimed to determine the best hydrocolloid for producing sports energy gel from chia seeds (*Salvia hispanica* L.). This study was a completed random-design study using one factor: the addition of 0.1% [...] Read more.

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Open Access Article (/2310-2861/7/4/266/pdf?version=1639636464)

[Stiffness Variation of 3D Collagen Networks by Surface Functionalization of Network Fibrils with Sulfonated Polymers (/2310-2861/7/4/266)]

by Philipp Riedl (https://sciprofiles.com/profile/1883023), Maria Schricker (https://sciprofiles.com/profile/1970927) and Tilo Pompe (https://sciprofiles.com/profile/1223518)

Gels **2021**, *7*(4), 266; https://doi.org/10.3390/gels7040266 (https://doi.org/10.3390/gels7040266) - 16 Dec 2021

Abstract Fibrillar collagen is the most prominent protein in the mammalian extracellular matrix. Therefore, it is also widely used for cell culture research and clinical therapy as a biomimetic 3D scaffold. Charged biopolymers, such as sulfated glycosaminoglycans, occur in vivo in close contact with [...] Read more.

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Open Access Article (/2310-2861/7/4/265/pdf?version=1639539474)

[Non-Invasive Assessment of PVA-Borax Hydrogel Effectiveness in Removing Metal Corrosion Products on Stones by Portable NMR (/2310-2861/7/4/265)]

by Valeria Stagno (https://sciprofiles.com/profile/1673435), Alessandro Ciccola (https://sciprofiles.com/profile/806313), Roberta Curini (https://sciprofiles.com/profile/author/WjltZUwwZlBtb1AvUktGT2ZzODNOUVdKalZPL2twd2dsNE5QY3d1T0xOST0=), Paolo Postorino (https://sciprofiles.com/profile/920588), Gabriele Favero (https://sciprofiles.com/profile/404296) and Silvia Capuani (https://sciprofiles.com/profile/1496865)

Gels **2021**, *7*(4), 265; https://doi.org/10.3390/gels7040265 (https://doi.org/10.3390/gels7040265) - 14 Dec 2021

Abstract The cleaning of buildings, statues, and artworks composed of stone materials from metal corrosion is an important topic in the cultural heritage field. In this work the cleaning effectiveness of a PVA-PEO-borax hydrogel in removing metal corrosion products from different porosity stones has [...] Read more.

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[Aerogels for Biomedical, Energy and Sensing Applications (/2310-2861/7/4/264)]

by Muhammad Tayyab Noman (https://sciprofiles.com/profile/224512), Nesrine Amor (https://sciprofiles.com/profile/552707), Azam Ali (https://sciprofiles.com/profile/1666237), Stanislav Petrik (https://sciprofiles.com/profile/author/eE9la3VUeVdzT0lHSkRkck9KUVhsNzZLS1lwaDlBL1plVnJhMXNzeUdKRT0=), Radek Coufal (https://sciprofiles.com/profile/author/MTJWMmhVRGJvS0ZPa3ZOdE92MmZPZUtjT2VXMDdjUFdyVyt1aDRDS1FSOD0=), Kinga Adach (https://sciprofiles.com/profile/108251) and Mateusz Fijalkowski (https://sciprofiles.com/profile/250626)

Gels **2021**, *7*(4), 264; https://doi.org/10.3390/gels7040264 (https://doi.org/10.3390/gels7040264) - 14 Dec 2021

Abstract The term aerogel is used for unique solid-state structures composed of three-dimensional (3D) interconnected networks filled with a huge amount of air. These air-filled pores enhance the physicochemical properties and the structural characteristics in macroscale as well as integrate typical characteristics of aerogels, [...] Read more.

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Open Access Review (/2310-2861/7/4/263/pdf?version=1658828742)

[Enhancing Stem Cell Therapy for Cartilage Repair in Osteoarthritis—A Hydrogel Focused Approach (/2310-2861/7/4/263)]

by Yisi Liu (https://sciprofiles.com/profile/1910206), Meng Wang (https://sciprofiles.com/profile/author/UUpnSWhkY0NUaTQ5M001VDF2TmlxblQrYVhlcFZudmNpRVEzNmdtdTBPMD0=), Yixuan Luo (https://sciprofiles.com/profile/author/SHF1MzNlRllrVjl1cGMvYnNEVHZNSXBuRWNkKytybE9JbnN0NWUxaDkyVT0=), Qianyi Liang (https://sciprofiles.com/profile/author/RDJJYlZxOHBvelhCeUFmN2Y4WlNBMUVkM1J4SjRuR3lzSlFLaURVc1MxYz0=), Yin Yu (https://sciprofiles.com/profile/1910097), Fei Chen (https://sciprofiles.com/profile/1909787) and Jun Yao (https://sciprofiles.com/profile/author/RXBVbmxmR1MzcUdQa0plVUliTExrbkJXc3h0Szd5Zk1TbXRQa29TVHB0TT0=)

Gels **2021**, *7*(4), 263; https://doi.org/10.3390/gels7040263 (https://doi.org/10.3390/gels7040263) - 14 Dec 2021

Abstract Stem cells hold tremendous promise for the treatment of cartilage repair in osteoarthritis. In addition to their multipotency, stem cells possess immunomodulatory effects that can alleviate inflammation and enhance cartilage repair. However, the widely clinical application of stem cell therapy to cartilage repair [...] Read more.

(This article belongs to the Special Issue Advanced Hydrogels for the Repair of Cartilage Defects (/journal/gels/special_issues/Hydrogels_Cartilage))

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Open Access Article (/2310-2861/7/4/262/pdf?version=1639394508)

[Synthesis and Characterization of Slow-Release Fertilizer Hydrogel Based on Hydroxy Propyl Methyl Cellulose, Polyvinyl Alcohol, Glycerol and Blended Paper (/2310-2861/7/4/262)]

by Semiu A. Kareem (https://sciprofiles.com/profile/1856702), Idayatu Dere (https://sciprofiles.com/profile/author/aVJ2MHVTZUt2YmtjWGk4allsZDF1SmV5NkhwZHNqTktnV2FBUjdkZlc3ND0=), Daniel T. Gungula (https://sciprofiles.com/profile/1965713), Fartisincha Peingurta Andrew (https://sciprofiles.com/profile/1259454), Abdullahi M. Saddiq (https://sciprofiles.com/profile/author/WWZKbHA5NklTMlRyRHllYzVlVzJuTGx1L3loN21DQnhBaWV1U2pHQ1UrRT0=), Elizabeth F. Adebayo (https://sciprofiles.com/profile/author/bEtPcExQUzFFN2s5NnFNcDNtU0JsR25VNHhRbmtNTStVY1kwVEVLWnEvdz0=), Vadlya T. Tame (https://sciprofiles.com/profile/author/c0YyUUcrYnl1S1hwM1dqYml2NjF2QVl3aUhlRnkyR0NJOVBaSDNuajVERT0=), Haruna M. Kefas (https://sciprofiles.com/profile/author/TVErbW1uSU9Ua2V4Zi8yK04rNzhlY3pmTllvRmFuVjBZSkQ3ejA2T1lxbz0=), Japari Joseph (https://sciprofiles.com/profile/author/endPVHVMRktYUnFiTFNNZlpRYk9UdHFXajgrc2h0cy9SbnFQK3JsL2RmVT0=) and David O. Patrick (https://sciprofiles.com/profile/805537)

Gels **2021**, *7*(4), 262; https://doi.org/10.3390/gels7040262 (https://doi.org/10.3390/gels7040262) - 13 Dec 2021

Abstract In this study, biodegradable slow-release fertilizer (SRF) hydrogels were synthesized from hydroxyl propyl methyl cellulose (HPMC), polyvinyl alcohol (PVA), glycerol and urea (SRF1) and HPMC, PVA, glycerol, urea and blended paper (SRF2). The fertilizer hydrogels were characterized by SEM, XRD and FTIR. The [...] Read more.

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Exploiting Urazole's Acidity for Fabrication of Hydrogels and Ion-Exchange Materials (/2310-2861/7/4/261)

by Saltuk B. Hanay (https://sciprofiles.com/profile/1877645), Ali Fallah (https://sciprofiles.com/profile/1670959), Efsun Senturk (https://sciprofiles.com/profile/author/cTdvdGlWNy9yWkw4ZmFWYjRNQmdHRVBvWktFNWpSVmVER0Z0V24wbGpYOD0=), Zeliha Yetim (https://sciprofiles.com/profile/author/L2FqQjg5S1pDVytZQ3RzOUVTcUtVNlJXbDJPWHB4RkNzK1FaSytMTWhHaz0=), Ferdows Afghah (https://sciprofiles.com/profile/803341), Hulya Yilmaz (https://sciprofiles.com/profile/1954513), Mustafa Culha (https://sciprofiles.com/profile/2013135), Bahattin Koc (https://sciprofiles.com/profile/790788), Ali Zarrabi (https://sciprofiles.com/profile/959071) and Rajender S. Varma (https://sciprofiles.com/profile/13409)
Gels **2021**, *7*(4), 261; https://doi.org/10.3390/gels7040261 (https://doi.org/10.3390/gels7040261) - 13 Dec 2021

Abstract In this study, the acidity of urazole (pKa 5–6) was exploited to fabricate a hydrogel in two simple and scalable steps. Commercially available poly(hexamethylene)diisocyanate was used as a precursor to synthesize an urazole containing gel. The formation of urazole was confirmed by FT-IR **[...] Read more.**
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Interaction between Negatively Charged Fish Gelatin and Cyclodextrin in Aqueous Solution: Characteristics and Formation Mechanism (/2310-2861/7/4/260)

by Qi Fang (https://sciprofiles.com/profile/1950556), Nao Ma (https://sciprofiles.com/profile/author/K2pCWFltQjFCdElaaUl3Sjh1ZHhFVDI1NUpQOCtjeGtBRkdkNUVtV0ZsQT0=), Keying Ding (https://sciprofiles.com/profile/author/dzNlV3NjaU9Nelh3dGJFcTZlUFdaUWRFazNKelVWbGFZb25CUVp3UlRMdz0=), Shengnan Zhan (https://sciprofiles.com/profile/1875480), Qiaoming Lou (https://sciprofiles.com/profile/author/cEUzWk93cldZVk5pbTJub0FTR3lCS2Z5RStoUFN5Sk1kVTF3OHQvU3MyOD0=) and Tao Huang (https://sciprofiles.com/profile/1723744)
Gels **2021**, *7*(4), 260; https://doi.org/10.3390/gels7040260 (https://doi.org/10.3390/gels7040260) - 13 Dec 2021

Abstract The effect that ratios of fish gelatin (FG) to α/β/γ cyclodextrins (α, β, γCDs) had on the phase behavior of a concentrated biopolymer mixture were comparatively investigated. This showed that the formed biopolymer mixture had the highest gel strength at ratios of FG–CD **[...] Read more.**
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Open Access Article (/2310-2861/7/4/259/pdf?version=1639633577)

New Formulations Loading Caspofungin for Topical Therapy of Vulvovaginal Candidiasis (/2310-2861/7/4/259)

by Noelia Pérez-González (https://sciprofiles.com/profile/1572275), Nuria Bozal-de Febrer (https://sciprofiles.com/profile/756962), Ana C. Calpena-Campmany (https://sciprofiles.com/profile/333616), Anna Nardi-Ricart (https://sciprofiles.com/profile/928922), María J. Rodríguez-Lagunas (https://sciprofiles.com/profile/86182), José A. Morales-Molina (https://sciprofiles.com/profile/author/VGwwMXJ0cjZkZ2dtWGwvTExlNW1BUXNVbzN3SEZIV09Oc2RFSlI6SkluRT0=), José L. Soriano-Ruiz (https://sciprofiles.com/profile/958204), Francisco Fernández-Campos (https://sciprofiles.com/profile/923404) and Beatriz Clares-Naveros (https://sciprofiles.com/profile/122756)
Gels **2021**, *7*(4), 259; https://doi.org/10.3390/gels7040259 (https://doi.org/10.3390/gels7040259) - 12 Dec 2021

Abstract Vulvovaginal candidiasis (VVC) poses a significant problem worldwide affecting women from all strata of society. It is manifested as changes in vaginal discharge, irritation, itching and stinging sensation. Although most patients respond to topical treatment, there is still a need for increase the **[...]**

Back to Top

[Injectable and In Situ Gelling Dextran Derivatives Containing Hydrolyzable Groups for the Delivery of Large Molecules (/2310-2861/7/4/150)](/2310-2861/7/4/150)

by Laura Di Muzio (https://sciprofiles.com/profile/1996269), Patrizia Paolicelli (https://sciprofiles.com/profile/127908), Chiara Brandelli (https://sciprofiles.com/profile/author/N2NranJ2ZEVMZ1o5a0l4VXh1SytCOE5sUzJkcDVveUJyTWg0SzNFNEgzND0=), Stefania Cesa (https://sciprofiles.com/profile/601884), Jordan Trilli (https://sciprofiles.com/profile/1760668), Stefania Petralito (https://sciprofiles.com/profile/392584) and Maria Antonietta Casadei (https://sciprofiles.com/profile/672266)

Gels **2021**, *7*(4), 150; https://doi.org/10.3390/gels7040150 (https://doi.org/10.3390/gels7040150) - 24 Sep 2021

Abstract Recently, we reported the synthesis and characterization of a new dextran derivative obtained by grafting polyethylene glycol methacrylate to a polysaccharide backbone through a carbonate bond. This moiety was introduced because it allows for the fabrication, through a photo-induced crosslinking reaction, of biodegradable **[...] Read more.**

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[Graphene Oxide-Chitosan Aerogels: Synthesis, Characterization, and Use as Adsorbent Material for Water Contaminants (/2310-2861/7/4/149)](/2310-2861/7/4/149)

by Filippo Pinelli (https://sciprofiles.com/profile/962892), Tommaso Nespoli (https://sciprofiles.com/profile/author/NjdLVk83TWw3Z0RyekhablRmZTQvWWZCVk1mVmJqeFBqWHo5Q2ZvSUJITT0=) and Filippo Rossi (https://sciprofiles.com/profile/358780)

Gels **2021**, *7*(4), 149; https://doi.org/10.3390/gels7040149 (https://doi.org/10.3390/gels7040149) - 24 Sep 2021

Abstract Porous aerogels, formed by subjecting precursor hydrogels using a freeze-drying process, are certainly one of the most studied and synthetized soft materials, thanks to their important features such as elasticity, swelling behavior, softness, and micro and nanosized pores, which guarantee their applicability in **[...] Read more.**

(This article belongs to the Special Issue Early Career Award on Gel-Related Science (/journal/gels/special_issues/early_career_award))

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