Alginate-Graphene Oxide Biocomposite Sorbent for Rapid and Selective Extraction of Non-Steroidal Anti-Inflammatory Drugs Using Micro-Solid Phase Extraction

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Abstract: *In this work, a bio-composite sorbent, alginate incorporated graphene oxide (Alg/GO) is prepared for the micro solid phase extraction of non-steroidal anti-inflammatory drugs (NSAIDs) from water samples. The sorbent was prepared in a suspended solution form at a ratio of 0.3:1 (w/v %) of graphene oxide (GO) and alginate (Alg). The chemical structure, morphology and surface area of the composite beads were characterized using Fourier Transform Infrared Spectroscopy (FT-IR), Scanning Electron Microscopy (SEM) and Brunauer–Emmett–Teller (BET). GO showed good miscibility and well dispersion through intermolecular hydrogen bonds and electrostatic interactions within the Alg matrix. The synthesized sorbent was applied for the determination of the selected drugs in a tap water sample using micro-solid phase extraction technique and was analyzed by high-performance liquid chromatography-ultraviolet detector (HPLC-UV). The results showed good linearity in the range of 10–1000 μg L^{-1} with correlation coefficients ($r \geq 0.9979$), low detection limits (LOD) between 3.1–4.6 μg L^{-1}, excellent relative recoveries in the range of 99.6–102.1% and good reproducibility (RSD ≤ 3.9%). Thus, these validated results showed that Alg/GO could be potential and useful as a bio-composite sorbent for micro-solid phase extraction for the analysis of targeted drugs from aqueous matrices.*

Keywords: *alginate; graphene oxide; non-steroidal anti-inflammatory drugs; micro-solid phase extraction*

■ INTRODUCTION

NSAIDs are the most commonly prescribed pharmaceuticals [1] used to treat pain, inflammation and fever in humans and animals [2]. Though it was thought that NSAIDs are harmless drugs, they do have some toxic effects in case of overdoses which can be highly risky for human and animals [3]. NSAIDs may cause gastrointestinal ulceration, inhibition of platelet aggregation, aplastic anemia, heap toxicity, cardiovascular risk and central nervous system depression [4]. Moreover, the persistence of NSAIDs in the aquatic environment resulted in an incomplete elimination by wastewater treatment plants (WWTPs) [5]. NSAIDs were found in the municipal WWTP influents, hospital WWTP effluents with very low concentrations in ng/L range [6]. The high graph of usages and partially removing of NSAIDs by WWTP caused a considerable concentration of the drugs in environmental waters all around the globe [6]. Thus, a precise and reliable analysis is needed for the determination and detection of NSAIDs at low concentration levels in environmental waters to ensure public safety and health.

Alginate is the most commonly used biopolymer composing of 1,4-linked residues of b-D-mannuronic (M) acid and a-L-guluronic acid (G) at different

proportions in the chain [7]. It is certainly obtained from the environment [8]. Alginate contains unique properties such as non-toxicity, hydrophilicity, biocompatibility and relatively low cost [9]. However, alginate shows some unsatisfactory properties such as weak mechanical resistance [10], low-stretch properties and loss of structural integrity [11], which limits its uses in many areas [7]. Thus, an effective solution is needed for the improvement of the situation. The development of an alternative biopolymer sorbent for the extraction of water pollutants has been received great attention [12] compared to conventional sorbents such as chitin, chitosan, [13] pineapple leaf powder, silica and alumina [14].

Nowadays, carbon nanomaterials such as carbon nanotubes (CNTs), graphene (G), GO and the combination of carbon nanomaterials (CNMs) with biopolymer alginate are the most recent sorbents. Nanoparticles (NPs) are well suited for miniaturized SPE [14]. Graphene oxide is a single-atomic-layered material which made of carbon, hydrogen, and oxygen molecules as a result of graphite crystals oxidation which is low-cost and plentiful [15]. GO includes many functional groups such as epoxy (–O), hydroxyl (OH), and carboxyl (–COOH) on the basal planes of GO [16]. These functional groups are sensitive sites for physical-chemical bonding with polymers and modify the Van der Waals connections among the nanofiller. Furthermore, the existence of many oxygen-containing groups on the GO surface make them steady and dispersible in polar solvents (water and organic coatings i.e. epoxy) [17]. Usually, a small quantity of GO is used as physical filler to improve the mechanical properties of polymer substrates [18]. Therefore, stronger hybrid structures have been discovered by mixing Alg with GO [1]. This study discusses a biocomposite beads Alg/GO as a solid sorbent for the determination of selected NSAIDs namely naproxen (NAP), diclofenac (DIC) and ibuprofen (IBU) from a water sample.

■ EXPERIMENTAL SECTION

Materials

NSAIDs namely naproxen (NAP), sodium diclofenac (DIC) and ibuprofen (IBU) were purchased from Sigma Aldrich (St. Louis, USA). HPLC grade organic solvents (methanol, (MeOH), acetonitrile (ACN), isopropanol (IPA) and tetrahydrofuran (THF) were obtained from Merck (Germany). Calcium chloride $(CaCl_2)\cdot 2H_2O$ and sodium acetate were obtained from HmbG Chemicals (Germany). Graphene oxide (GO) was purchased from Advance GO company (Germany). Sodium hydroxide (NaOH) and hydrochloric acid (HCl) (37%) were obtained from Merck (Darmstadr, Germany). Alginate was purchased from Qrec (New Zealand). Sodium chloride (NaCl) was obtained from Sigma-Aldrich (St. Louis, USA). Ultrapure water was obtained from a Barnstead Nanopure (Thermo Scientific).

Procedure

Chromatographic conditions

The instrumental analysis of NSAIDs was performed using Agilent Technologies 1100 series HPLC system (Agilent Technologies, USA) equipped with solvent degasser, autosampler with a 5 µL loop, quaternary pump, column thermostat and ultraviolet (UV) detector. The chromatographic separation was carried out on a Zorbax Eclips Plus C_{18} (2.1 × 100 mm, 3.5 µm, Agilent Technologies, USA). The mobile phase consisted of (A) acetonitrile and (B) 25 mM of sodium acetate buffer (CH_3COONa, pH = 3.25) at 60:40 (A:B) composition of isocratic elution. Prior to the analysis, the chromatographic system was stabilized for 30 to 60 min. The flow rate was set at 0.2 mL min^{-1}, the injection volume was 10 µL and the column thermostat was set at 23 °C. Detector wavelength was set at 220 nm and the chromatographic data was recorded by Agilent Chemstation software.

Preparation of Alg/GO beads

The procedures used for the preparation of Alg/GO beads were modified from the literature [10,19]. The modification includes optimizing the concentrations of Alg (1 w/v %), GO (0.3 w/v %), and the flow rate of the syringe pump (0.6 mL min^{-1}) used for dripping Alg/GO solution into $CaCl_2$ solution. The concentration of both Alg and GO can affect the performance efficiency of the composite beads and the

pump's flow rate causes to provide homogeneous beads. The composite beads were prepared using the suspension method. Initially, 1.0 g of sodium alginate was added in 70 mL of deionized water and stirred at 60 °C for 2 h and 30 min. Meanwhile, 0.3 g of GO was dispersed separately in 30 mL of deionized water under sonication for 1 h. Then, GO dispersion solution was added into the sodium alginate solution dropwise under vigorous stirring in 1 h. Subsequently, the mixture was stirred for another 1 h to obtain a hybrid sol. The mixture solution was dripped using a syringe pump (New Era-300 pump system, USA) with a flow rate of 0.6 mL min^{-1} into 300 mL of the 1.5 M $CaCl_2$ solution while a gentle and steady stirring was going on to avoid sticking and agglomeration of the beads. The $CaCl_2{\cdot}2H_2O$ solution including beads was kept in the chiller overnight. Alg/GO composite beads were formed upon contact with calcium ions. After removal from the calcium chloride bath using an 11 μm filter paper, the beads were rinsed thoroughly with deionized water and dried in an oven at 50 °C for 24 h.

Characterization of Alg/GO beads

FT-IR (Diamond window of NICOLET iS10 FT-IR) was used to determine the surface chemistry and functional groups of Alg, GO and the synthesized Alg/GO beads. The analysis was done in the wavenumber range of 500–4000 cm^{-1} at a resolution of 2 cm^{-1} and 32 number of scans. The porosity and surface area feature of Alg/GO beads were determined by BET (An automatic micrometric ASAP-2060 (Agilent, USA). SUPRA 40VP 31-31 SEM was used to observe the surface structure, morphology (shape and size) and the surface composition of Alg and the synthesized Alg/GO sorbent beads.

Micro solid phase extraction (μ-SPE) procedures

μ-SPE was conducted by adding 0.15 g of Alg/GO beads containing 0.019 g of GO in 10 mL of the aqueous mixture (pH = 3). NSAIDs were extracted by stirring the sample at 1000 rpm for 30 min. To desorb the extracted NSAIDs, 300 μL of IPA as a desorption solvent was added and the mixture was sonicated for 10 min. To concentrate the analytes, the NSAIDs mixture was blown with nitrogen gas. Finally, about 10 μL of the extracted sample was injected to HPLC-UV system.

■ RESULTS AND DISCUSSION

Fourier Transform Infrared Spectroscopy (FT-IR) Analysis

As shown in Fig. 1, the FTIR spectra of GO showed the peaks at 3208, 1716 and 1615, which contributed to –OH, –COOH, C=C in the sp^2 carbon skeletal network, and 1044 cm^{-1} can be –C–O groups [7]. For Alg spectra, the peaks at 3243, 1594 cm^{-1} represent the asymmetric stretching vibration of –OH and $–COO^-$, respectively [7]. The band at 1407 cm^{-1} attributes to the presence of $–CH_2$ (bending) and 1025 cm^{-1} contributed to C–O–C stretching mode [20].

Comparison spectra of absorption bands are shown in Table 1. The spectrum of Alg/GO does not have a significant change as compared to the spectrum of the pristine Alg. Probably, this could be due to the small portion (0.3 w/v %) of GO present in the nanocomposite beads [21]. The downshifted bands of

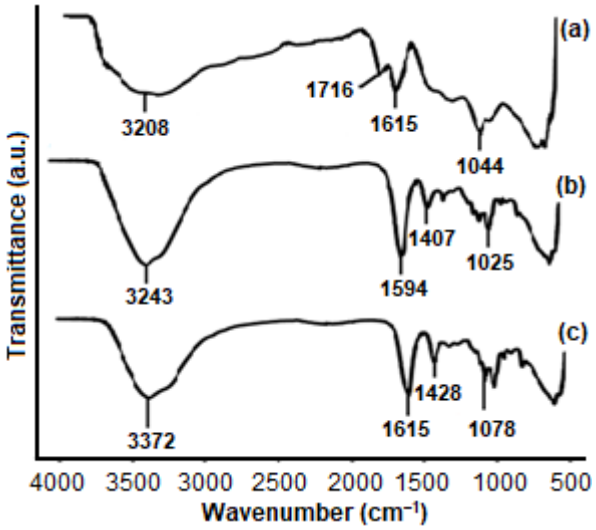

Fig 1. FTIR spectra pattern of (a) GO, (b) Alg and (c) Alg/GO beads

Table 1. Comparison of FTIR absorption bands of GO, Alg, and Alg/GO.

Vibration	GO (cm^{-1})	Alg (cm^{-1})	Alg/GO (cm^{-1})
–OH	3208	3243	3372
–COOH	1716	-	1615
C–O	1045	1025	1078
$–COO^-$	-	1594	1428

–OH vibration mode at 3372 [7] and –COOH (asymmetric stretching) at 1615 cm^{-1} [20] indicates intermolecular hydrogen bonds between GO layers and sodium alginate chains, proved good miscibility between Alg and GO [7]. Other peaks at 1428 and 1078 cm^{-1} contributed to symmetric $–COO^-$ and C–O stretching mode [19]. The shifting of vibration bands shows that π–π stacking and electrostatic interactions occurred within the Alg/GO matrix [7].

Surface Area and Pore Analysis

The Brunauer-Emmett-Teller surface area (BETs) was determined through BET procedures. Barrett-Joyner- Halenda (BJH) adsorption cumulative volume of pores (Vc) was valued between 1.7000 and 300.0000 nm width. The adsorption average pore width (W) was calculated by the BJH. Fig. 2 shows the linear plot of Alg/GO adsorption/desorption isotherms. It specifies that Alg/GO relates to type 1V isotherms according to IUPAC classification, which belongs to mesoporous materials [22]. A hysteresis loop (type H3) also was observed and this type of desorption isotherm indicating the presence of slit-shaped pores resulting from the aggregation of plate-like particles [22-23]. In addition, the rapid uptake starting from 0.8 to 1.0 of relative pressure (P/P^0) values, demonstrates the presence of numerous mesopore structures within the Alg/GO beads [20].

Textural properties of Alg/GO beads were evaluated from BJH methods. From the results, Alg/GO shows lower BET_S value (4.98 m^2/g) compared to pure GO (166 m^2/g) and almost similar value to pure alginate (5 m^2/g) [19] or higher value according to literature reported by Fei and co-workers (4 m^2/g) [20]. The low surface area of Alg/GO compared to pure GO might be due to the consequence of the re-stacking and reduction of the distance between GO sheets that occurred during the drying process. This phenomenon is similar to a study reported by Saraf and co-workers indicated that the morphology and porous characteristics of the beads can be affected by the drying methods [24]. Besides, decreasing of Alg/GO surface area could be because of the agglomerations of GO layers during the drying procedure due to being remarkable van der Waals force between every

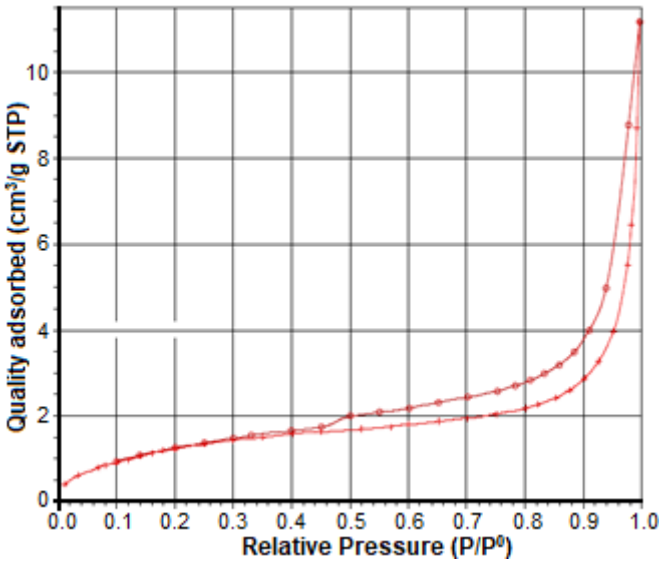

Fig 2. Surface area and pore analysis of Alg/GO beads by BET

single layer of GO [25]. However, the surface area is not the only main factor to measure the adsorption ability, the pore width also plays a significant role in measuring the adsorption capacity [25]. Thus, it is expected the pore width of Alg/GO beads (4.86 nm), which is higher than pore width of pure Alg (3.1 nm) and pure GO (2.4 nm) would contribute to the adsorption process [19]. Meanwhile, the cumulative total pore volume of Alg/GO beads was found to be 0.013428 cm^3/g. The results demonstrate that the Alg/GO beads has large pore that is favorable to sorption process.

Scanning Electron Microscopy (SEM)

Alg/GO beads have a relatively rough surface morphology, comprised of mesoporous structure (the average pore width is 4.86 nm) which facilitates the adsorption of NSAIDs and it is shown in Fig. 3(a). In addition, it seems that mostly there are homogenous pores in all parts of its surface. The homogeneous distribution of GO into Alg matrix which indicates comprehensive compatibility between functional groups such as -COOH, -OH, and $-COO^-$ that existed in GO and Alg matrix [10]. Fig. 3(b) showed the exhibits of the pure alginate beads surface morphology, which includes a less rough surface with a smaller size of pores compared to Alg/GO beads. As a comparison, in Fig. 3(a) and (b),

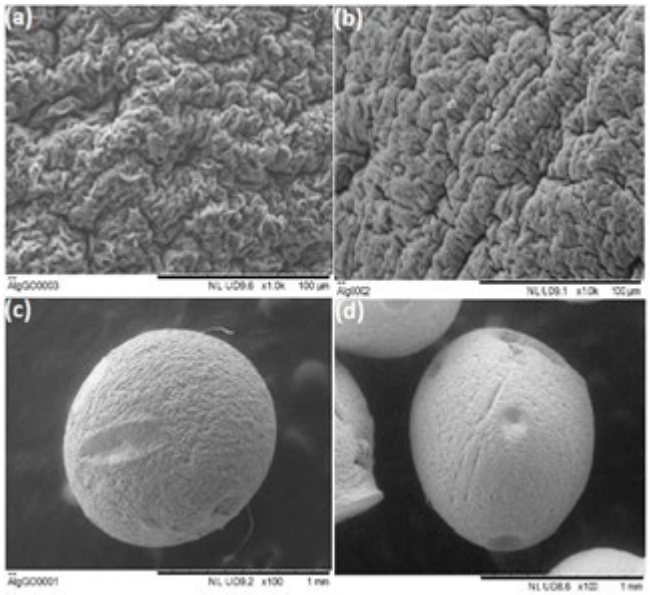

Fig 3. SEM images of (a) Alg/GO x 10 k magnificent, (b) Alg beads x 10 k magnificent, (c) Alg/GO whole beads and (d) Alg beads

spectacularly it can be seen that the impregnation of GO into Alg was increased the size of pores and developed the arrangement of pores. It was reported that incorporation of GO into Alg matrix increased the number of active sites of Alg [20].

Optimization of Alg/GO - μ-SPE

To enhance the performance of D-μ-SPE technique using the synthesized Alg/GO, several parameters such as extraction time, sample pH, salt addition, desorption solvent, desorption time, string speed, desorption solvent volume and mass of sorbent were investigated to establish the optimum extraction conditions.

Effect of sorbent mass and sample pH

Nano-sized materials mostly include high surface areas. Therefore, a good recovery can be obtained using the small amount of nanosized sorbents [3]. The effect of sorbent amount on the extraction efficiency was studied using various quantity of sorbent in the range of 0.05–0.25 g. Fig. 4(a) showed the relationship between the amounts of sorbent with the peak area of NSAIDs. It was found that, 0.15 g of sorbent exhibited the highest peak areas of each NSAIDs. Increasing the amount of sorbent more than 0.15 g decreased the peak area of NSAIDs with the drastic decreasing for DIC. Thus, 0.15 g of the sorbent was chosen as the optimum value and used in subsequent experiments. Sample pH was the main parameter that extremely affected the extraction

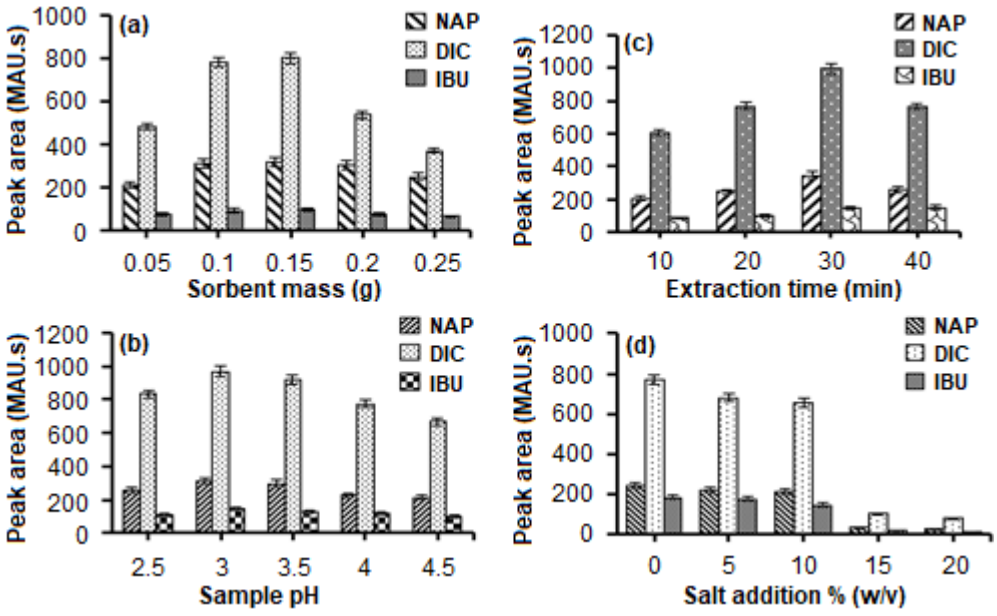

Fig 4. Effects of (a) mass of sorbent, (b) sample pH, (c) extraction time, and (d) salt addition on Alg/GO-D-μ-SPE-HPLC-UV of NSAIDs from spiked water sample. Error bars describe the standard deviations of results, n = 3

efficiency. Most of the NSAIDs can present in water into both ionized and unionized forms due to its acidic moiety. Unionized form is considered as an easier way for the extraction of the analytes compared to their ionized form [26]. To extract the compounds efficiently, it was necessary to unionize the interest analytes by decreasing their solubility into the sample solution and guarantee their good transmission to the extractor phase. These conditions can be obtained by setting the pH of aqueous sample into acidic ranges [1]. The dissociation consistent (pK_a) values of the target compounds NAP, DIC and IBU were 4.2, 4.15, 4.51, respectively. The dissociation consistent (pK_a) values of the target compounds NAP, DIC and IBU are 4.2, 4.15, 4.51, respectively [1]. Thus, the extractions were accomplished under several pH conditions ranging from pH 2.5 to 4.5 as presented in Fig. 4(b). 1M HCl and NaOH were used to adjust the pH values. Peak area of each NSAIDs increased when the pH was increased from 2.5 to 3. However, the peak areas decreased when the pH was increased to 3.5 and above. This observation was due to changing the NSAIDs to ionized and their conjugated form in sample pH higher their pK_a values [26]. Therefore, pH 3 was selected as the optimum pH for further analysis.

Effect of extraction time and salt addition

One of the most relevant parameter issues which can increase the precision and sensitivity of the extraction method was the sorption time because it was necessary to allocate sufficient time to warrant the equilibrium between the aqueous phase and sorbent [3]. In this study, the extraction times were examined within 10 to 40 min. The optimum extraction time for the selected NSAIDs was found at 30 min and there was no remarkable increase in the peak areas of NSAIDs after the extraction time was extended above 30 min as shown in Fig. 4(c). There was a decrease in the peak areas when the extraction time was increased to more than 30 min. This might be due to back-extraction of NSAIDs from adsorbent into sample solution [26-27]. Therefore, 30 min was selected as the optimum extraction time. The main purpose of adding salt was to increase the ionic strength of the sample solution and reduce the solubility of the target compounds in the aqueous sample. Increasing of salt strength or salting out effect paves the way for good participation of analytes during extraction process [1,28]. In this study, the effect of salt addition on the efficiency of extraction method was evaluated by adding of NaCl at different concentrations in the range of 0–20 % (w/v) in the sample solution. The highest peak area of the target NSAIDs was obtained without adding any NaCl as shown in Fig. 4(d). The reason for decreasing the extraction efficiency of NSAIDs when NaCl was added was might be due to the increasing of viscosity of the solution. Viscosity decreased the frequency of diffusion of the analytes toward adsorbent [29]. Therefore, in this study, addition of NaCl was not applied.

Effect of stirring speed and desorption solvent

In this work, the stirring speed ranging from 500 to 1250 rpm were studied. Increasing stirring speed accelerates in obtaining of equilibrium between analytes and sorbent [29]. It was found that the extraction efficiency increased with stirring speed and reached a maximum at 1000 rpm as shown in Fig. 5(a). High stirring speed created bubbles, which can slow down the diffusion rate of analytes toward sorbent [29-30]. Thus, 1000 rpm was selected as the optimum stirring speed. From previous studies, there were three common parameters influenced the desorption process, namely, the polarity of solvents [29], the solubility of the target analytes and the compatibility of the instrument [26]. Considering the principle "like dissolve like" substances dissolve in a solvent whenever they have similarity in their chemical characteristics particularly their polarities [31]. In this study, solvents such as THF, ACN, IPA, and MeOH were evaluated as desorption solvents, their polarities increased from THF to MeOH. From the result, It was observed that IPA, which was moderately polar solvent gave the highest desorption efficiency because its polarity was similar to desired analytes. Thus, the "like dissolve like" aphorism could be implemented and gave the best result among other solvents as showed in Fig. 5(b). Therefore, IPA was chosen as desorption solvent for further analysis.

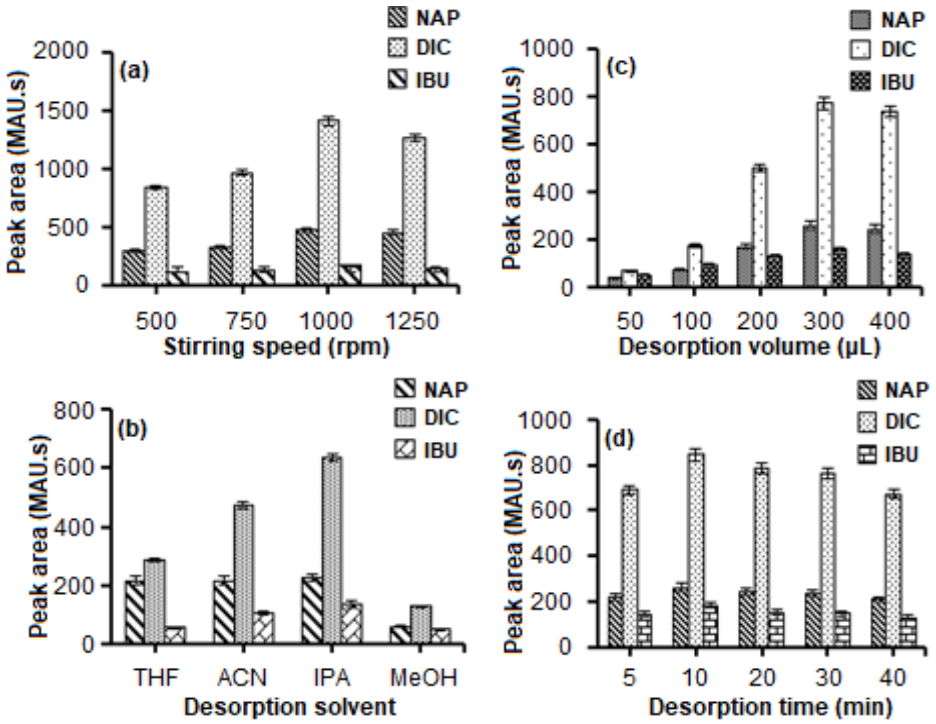

Fig 5. Effects of (a) stirring speed, (b) desorption solvent, (c) desorption volume, and (d) desorption time on Alg/GO-D-µ-SPE-HPLC-UV of NSAIDs from spiked water sample. Error bars describe the standard deviations of results, n = 3

Table 2. The optimum conditions of Alg/GO-D-µ-SPE technique to extract the NSAIDS form water sample

Operating parameters	Optimum conditions
Mass of sorbent	0.15 g
Extraction time	30 min
Sample pH	3
Salt addition	0% w/v
Desorption time	10 min
Desorption solvent	IPA
Desorption volume	300 µL
Stirring speed	1000 rpm

Effect of desorption solvent volume and desorption time

The volume of desorption solvent could affect the concentration of the extracted analytes as the low volume was higher than the concentration of the analytes [32]. To evaluate the volume of desorption solvent, various volumes in the range of 50–400 µL were evaluated. The highest recovery was achieved when 300 µL of desorption solvent volume was used as shown in Fig. 5(c). Therefore, 300 µL was selected as the optimum volume of desorption solvent. Desorption time was another important factor which could affect the peak area of the analytes. In this study, various desorption times were examined within 5–40 min as shown Fig. 5(d). A desorption time of 10 min led to highest peak area of each NSAIDs and gradually decreased as a result of read sorption of the target analytes [33]. Thus, 10 min was adopted as the optimum of desorption time for further analysis. The optimum D-µ-SPE parameters are tabulated in Table 2.

Method Validation and Analytical Performance of Alg/GO-µ-SPE

The proposed method of Alg/GO-µ-SPE-HPLC-UV was validated under optimized parameters for the analysis of selected NSAIDs from a water sample. A matrix-match calibration method was conducted to validate the Alg/GO-µ-SPE for the extraction of three targeted analytes namely NAP, DIC and IBU. The method was validated and assessed using the limit of detection (LOD), limit of quantification (LOQ), and linearity. The LOD and LOQ were determined based on the linear regression method using the formulas $LOD = \frac{3S_\sigma}{m}$ and $LOQ = \frac{10S_\sigma}{m}$ respectively, where S_σ was

Table 3. Validation data of Alg/GO-D-μ-SPE-HPLC-UV of NSAIDs from spiked tap water sample

Sample	Analyte	Linear Range (μg L^{-1})	Correlation Coefficient, r	LOD (μg L^{-1})	LOQ (μg L^{-1})	Precision (RSD, %) (n = 3)
Tap water	NAP	10 - 1000	0.9993	3.1	9.6	3.7
	DIC	10 – 1000	0.9979	4.3	8.7	6.9
	IBU	10 – 1000	0.9981	4.6	9.3	4.8

NAP = Naproxen, DIC = Diclofenac, IBU = Ibuprofen, HPLC = High performance liquid chromatography, LOD = Limit of detection, LOQ = Limit of quantification, RSD = relative standard deviation

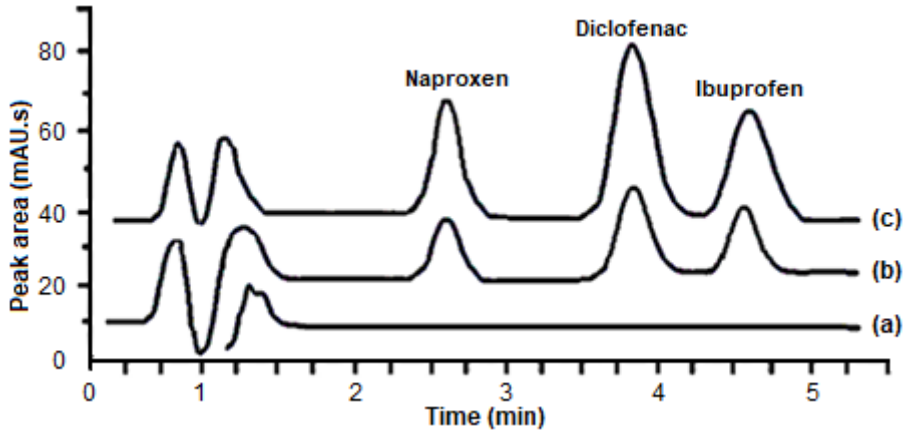

Fig 6. Chromatograms of tap water at (a) non-spiked, (b) 500 μgL^{-1}, and (c) 1000 μgL^{-1} spiked sample

Table 4. Relative recoveries (%) and method precisions (RSD%, *n=3*) at two different concentrations for Alg/GO-D-μ-SPE-HPLC-UV in tap water sample.

Sample	Analyte	Average relative recoveries (n = 3), % (RSD, %)	
		500 μg L^{-1}	1000 μg L^{-1}
Tap water	NAP	102.1 (2.4)	99.6 (2.7)
	DIC	99.9 (2.6)	101.0 (1.2)
	IBU	100.9 (3.9)	100.0 (2.5)

a standard deviation and m was a slope of the calibration curve. Calibration curves were obtained by plotting the peak areas versus concentration using the least-squares method. Good linearity was achieved in the range of 10–1000 μg L^{-1} for NAP, DIC and IBU with correlation coefficients (r ≥ 0.9979) and LOD were in the range of 3.1–4.6 μg L^{-1} for tap water sample. The results are tabulated in Table 3.

Relative recovery studies of the proposed method were conducted by spiking tap water to give final concentrations of of 500 and 1000 μg L^{-1}. Result obtained (Table 4) showed excellent relative recoveries in the range of 99.6–102.1% and good reproducibility (RSD ≤ 3.9%). Fig. 6 showed the typical HPLC-UV chromatograms of non-spiked and spiked tap water sample at two different concentrations respectively.

Comparison of Alg/GO-μ-SPE-HPLC-UV with Other Reported Methods

The performance of Alg/GO-μ-SPE and other reported methods for the extraction and determination of NSAIDs from water samples were tabulated in Table 5. Each published method provided advantages and disadvantages. Membrane protected C_{18} coated stir bar sportive (C_{18}-MPSBSE) extraction provided good sensitivity and achieved excellent recoveries but this method suffered from long extraction time (60 min) [34]. Oasis rotating-disk sportive extraction (Oasis-HLB-RDSE) provided a low limit of detection. However, the extraction was longer compared to C_{18}-MPSBSE [35]. It was observed that magnetic matrix solid-phase dispersion coupled to high-performance liquid chromatography (M-MSPD–HPLC) provided fast extraction time and good sensitivity. However, this

Table 5. Comparison of the proposed method with other microextraction methods applied for the determination of NSAIDs in water samples

Analytical Methods	Linear Range (μgL^{-1})	LOD (μgL^{-1})	Extraction Time (min)	Sample Volume (mL)	Recovery %	Ref.
C_{18}-MPSBSE–HPLC–UV	20-1000	6.90-7.69	60	20	91.9-93.9	[34]
Oasis-HLB-RDSE-HPLC-DAD	5-2000	0.001-0.003	100	100	71-104	[35]
Magnetic-MSPD-HPLC	50-700	7-10	30	200	94-100	[36]
MNPs-D-μ-SPE-HPLC-UV	5-1500	1.5-3.5	5	5	64-76.7	[37]
Alg/GO-μ-SPE-HPLC-UV	10-1000	3.1-4.6	30	10	99.6-102.1	Current work

Non-steroidal anti-inflammatory drugs (NSAIDs), limit of detection (LOD), membrane protected stir bar sportive extraction (MPSBSE), rotating-disk sportive extraction (RDSE), high-performance liquid chromatography-diode array detector (HPLC-DAD), magnetic matrix solid-phase dispersion (magnetic-MSPD), hollow fiber liquid-phase microextraction ultra-performance liquid chromatography-tandem mass spectrometry (HF-LPME-UPLC-MS), Magnetic nanoparticles-dispersive micro solid phase extraction high-performance liquid chromatography-ultraviolet (MNPs-D-μ-SPE-HPLC-UV), alginate graphene oxide (Alg/GO)

technique required a large volume of the sample (200 mL) [36]. Magnetic nanoparticles based on dispersive micro solid phase extraction coupled to high-performance liquid chromatography-ultraviolet detector (MNPs-D-μ-SPE-HPLC-UV) provided a low limit of detection and rapid extraction. However, this method provided relatively lower recoveries [37]. Alg/GO-μ-SPE-HPLC-UV method showed short extraction time (30 min), good sensitivity, and excellent recoveries in the range of 99.6–102.1%. This method was compatible with the green chemistry concept as alginate was biodegradable. Alg/GO-μ-SPE-HPLC-UV required low volume of organic solvent, simple steps and comparable efficiency with other reported methods.

■ CONCLUSION

This study showed Alg/GO bio-composite as a new sorbent with a great feature such as good miscibility and well dispersion through intermolecular hydrogen bonds and electrostatic interaction within the alginate matrix. It has proven that Alg/GO sorbent relates to the type 1V mesoporous materials with a hysteresis loop of type H_3 indicating the presence of slit-shaped pores resulting from the aggregation of plate-like particles. The resulting materials were adapted for the determination of selected NSAIDs in tap water sample showed good linearity ($r \geq 0.9979$) over a concentration range of 10–1000 μgL^{-1} with acceptable LODs between 3.1–4.6 $\mu g\ L^{-1}$. The proposed method also revealed excellent relative recoveries in the range of 99.6–102.1% and good reproducibility (RSD ≤ 3.9%). It is envisaged that Alg/GO bio-composite sorbent offered high selectivity, good sensitivity and potentially successfully applied for extraction of NSAIDs from tap water sample using micro-solid phase extraction method.

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