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Effect of Gum Arabic on the Clarity of Artificially Turbid Water and Ground Water Systems

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الملخص

شجعت التكلفة العالية لاستخدام البوليمرات الاصطناعية مثل بولي أكريلاميد في عملية تنقية المياه، وسمية المونومرات الناتجة عن تحضير تلك البوليمرات العديد من الباحثين على إيجاد بديل جيد لتنقية المياه العكرة. تم تنفيذ هذا البحث لتحديد فاعلية الصمغ العربي (GA) كمساعد تخثر طبيعي في معالجة المياه العكرة اصطناعياً (الماء المشبع بالسيليكا (SiO_2)، المكون الرئيسي للصخور) وأنظمة مياه الشرب الجوفية. أظهرت النتائج التجريبية أن أعلى كفاءة للصمغ العربي زادت صفاء المياه تم الحصول عليها عندما كان محتواه 5٪ (نسبية وزن الصمغ لحجم المياه). تم تأكيد ذلك من خلال تقليل التعكر من NTU 1269 إلى 56 NTU. تمت دراسة حركية الارتباط بين الصمغ والسيليكا حاسوبيا ووجد أن نموذج تحلل طورين مناسبًا ($R^2 \sim 1$) للبيانات الحركية عند نسب 0.001، 0.01، 0.1 ٪ من الصمغ المضاف، وهذا يقترح أنه عند هذه النسب المنخفضة من الصمغ تظل بعض جسيماتSiO_2 معلقة في أعلى المحلول المائي والبعض الاخر مترسب مع الصمغ أسفل المحلول، في حين أن تحلل طور واحد فقط يناسب البيانات جيدًا عند إضافة 1 و5 ٪ من الصمغ، مما يعني ارتباط $GA\text{-}SiO_2$ كان ارتباطا كاملا. علاوة على ذلك، لوحظ اعتماد اضمحلال التعكر على محتوى GA حيث لوحظ الحد الأدنى من عمر الارتباط (دقائق9 = τ) عند 5٪. كشفت التحليلات الفيزيائية والكيميائية (لعدد ثلاث أبار جوفية في مدينة بنغازي) أن الصمغ فعال في الحد من التعكر، والمواد الصلبة الذائبة الكلية، والقلوية الكلية والعسر الكلي للمياه ولديه القدرة على تنقية المياه من خلال ترسيب المعادن غير المرغوب فيها. يمكن أن يكون هذا البوليمر الطبيعي الصديق للبيئة والاقتصادي مادة واعدة لاستخدامها في معالجة المياه الجوفية.

الكلمات المفتاحية: الصمغ العربي، العكارة، السيليكا، الخواص الحركية، القلوية الكلية، العسر الكلي للمياه.

Abstract

The high cost of using synthetic polymers such as polyacrylamides in the water purification process, and their monomers toxicity produced from the polymer synthesis encouraged many researchers to find a good replacement to clarify turbid water. This work was carried out to determine the effectiveness of Gum Arabic (GA) as a natural coagulant aid in the treatment of artificially turbid water (water saturated with silica (SiO_2), the main component of rocks) and ground drinking water systems, which is rich in rocks. The experimental results showed that the highest efficiency for GA as a water clearer was increased by increasing its content to 5 wt %. This was confirmed by a reduction in the turbidity from 1269 NTU to 56 NTU. Interaction kinetic fits specified that the two-phase decay model was found to be the proper fit ($R^2 \sim 1$) for the kinetic data at 0.001, 0.01, 0.1 wt% of added GA. This proposes that at a low content of GA molecules, some SiO_2 particles remain suspended in bulk solution, while only one phase decay fitted the data well when 1 and 5 wt% of GA were added, which means a complete GA-SiO_2 interaction. Furthermore, the turbidity decay dependence on the GA content was noted as a minimum interaction lifetime (τ = 9 min) has been observed at 5 wt%. The physicochemical analyses have revealed that GA is effective in reducing turbidity, total dissolved solids, total alkalinity and total hardness of water and has the ability for water purification by owning unwanted minerals and hardness removal characteristics. This eco-friendly and economical natural polymer could be a promising material to use in groundwater treatment.

Keywords: Gum Arabic, Turbidity, Silica, Kinetics, Total Alkalinity, Total Hardness

1. INTRODUCTION

Coagulation is used in the treatment of surface, ground, and industrial wastewater to remove dissolved solids and turbidity by using conventional chemical-based coagulants such as alum ($AlCl_3$), ferric chloride ($FeCl_3$), and poly (Aluminium chloride) (PAC)[1]. Although the effectiveness of these chemicals as coagulants was widely acknowledged, their use was associated with several drawbacks, including ineffectiveness in low-temperature water, relatively high procurement costs, negative effects on human health, the production of large volumes of sludge, and a significant impact on the pH of treated water[2]. So polymers could be a good candidate for water clarification, but the high cost of using synthetic polymers such as polyacrylamides in the water purification process, and their monomers toxicity produced from the polymer synthesis encouraged many researchers to find a good replacement to clarify turbid water [3-5].

Gum Arabic or Acacia Gum is a natural polysaccharide derived from the exudates of A. Senegal and A. Seyal trees. Gum Arabic acts as an efficient emulsifier and a stabilizer in food and cosmetic products containing oil-water interfaces. Many researchers recognize that Gum Arabic consists of mainly three portions [6-10]. The major part is a highly branched polysaccharide consisting of a glucose backbone with linked branches of arabinose and ramose, which terminate in glucuronic acid. A smaller fraction is a higher molecular weight arabinogalactan-protein complex in which arabinogalactan chains are covalently linked to a protein chain through serine and hydroxyproline groups. The attached arabinogalactan in the complex contains glucuronic acid. The smallest fraction having the highest protein

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content is a glycoprotein which differs in its amino acid composition [7,10,11].

The physical properties of Gum Arabic, recognized as quality factors, include moisture, total ash, volatile matter and internal energy. GA is a natural macromolecule consisting of hydrophilic carbohydrate and hydrophobic protein components emulsifier which adsorbs onto the surface of oil droplets while the hydrophilic carbohydrate component inhibits flocculation and coalescence of molecules through electrostatic and steric repulsions in food additives[7]. Moisture content facilitates the solubility of hydrophilic carbohydrates and hydrophobic proteins in GA polymer. Total ash content is used to determine the critical levels of foreign matter, acid-insoluble matter, and salts of magnesium, calcium, and potassium [7,10].

The cationic compositions of ash content are used to determine the specific levels of heavy metals in Gum Arabic [10]. Gum Arabic is a solid of a pale to orange-brown color which, when ruptured secretes a vitreous

substance. Gum Arabic of excellent quality is tear-shaped, round, with an orange-brown color. After it is crushed or shattered, the pieces are paler in color and have a vitreous appearance. Contrary to other vegetable gums, gum Arabic dissolves very well in water (up to 50%). The viscosity of A. Senegal is weak (16 mL/g on average). The resulting solution is colorless, tasteless and does not interact easily with other chemical compounds [7,10,11]. Chemically, gum Arabic is a slightly acidic complex compound, made up of glycoprotein and polysaccharides. The principal polysaccharide is Arabic acid, a polysaccharide linking a D-galactose with branches composed of L arabinose, L-rhamnose and D-glucuronic acids [6-8,10,12].

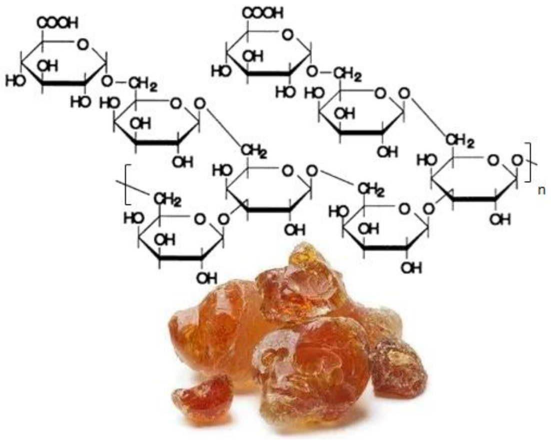

Figure 1. Structure and Resin of Gum Arabic

This work aims to introduce GA as an effective coagulant aid in the treatment of ground drinking water, which is reached in rocks. The interaction of GA with the silica suspended in water will also be investigated using the turbidity technique.

2. EXPERIMENTAL

2.1 Materials

In this work, GA from soluble pure, as shown in Figure 1 was obtained from a local Sudanese company and used as received. Silica (SiO_2) from (Riedel-De Haen ag Seelze-Hannover). Groundwater samples used for this work were collected from three different wheels in Benghazi (Libya) and were coded as S1, S2, and S3, respectively. Samples were collected in new plastic bottles pre-sterilized with ethanol and then were analyzed immediately in the laboratory.

2.2 Physicochemical Analyses

The turbidity of the water samples was measured on a conventional turbidity meter; Lamotte 2020 We Turbidimeter (Figure 2). Firstly, the instrument was switched on and calibrated with distilled water poured into a vial, and then 5 mL of the water sample was determined.

Total dissolved solids (TDS) were measured using a multimeter analyser that determined different parameters according to the selected mode. Initially, the instrument was switched on and calibrated with distilled water. 5ml of water sample was poured into a vial, then the electrode of the instrument was inserted into the vial and the TDS mode button was pressed for reading each sample.

The total alkalinity of the water sample was measured by titrating it with a standard solution of HCl.

Total hardness (amount of Ca^{2+} and Mg^{2+} ions dissolved in water sample was determined by using a standard solution of EDTA.

2.3 Kinetic Experiment

The correct proportions of GA were measured and mixed with 10 wt% of silica suspensions (artificial turbid water), and then, immediately, turbidity was recorded as a function of time and directly obtained in the form of a graph. This graph was fitted to an exponential function via Graph Pad Prism Software®, and consequently, the kinetic parameters were determined.

Figure 2. Turbidity measurements by 2020 Nephelometer.

2.4 Statistical Analysis

Results were expressed as means ± standard division of the mean (n = 3).

3. RESULTS AND DISCUSSION

To examine the efficiency of GA polymer as a good coagulant aid in the treatment of turbid water, artificial water suspended with silica at different amounts of the polymer was investigated. Figure 3 shows the turbidity of the suspension solution as a function of GA content. It is well known that the aggregation of suspended particles in water creates a turbid system [13]. The addition of polymer to the solution exhibited a rapid reduction in turbidity. It decreased from 955 NTU to 372 NTU and from 1269 NTU to 56 NTU upon adding GA polymer from 0.001 wt% to 5 wt%.

Figure 3 also depicts the kinetic study for GA interaction with SiO_2 suspension generated, which was investigated by monitoring the change in turbidity values of bulk solution as a function of time in minutes scale. The study was conducted at room temperature and natural pH. During adding different concentrations of polymer, the values of turbidity decreased exponentially after one hour from the beginning of the GA-silica interaction. Specifically, the turbidity of bulk solution decreased from 400 NTU to 75 NTU after 60 minutes of adding GA polymer. In order to fit interaction kinetic data, a two-phase decay model (2) was selected to fit for the kinetic data at 0.001, 0.01, 0.1 wt% of added GA, but one phase decay (1) was nominated to fit at the addition of 1 and 5 wt% of GA.

$Td = (Td_0 - Td_p)*\exp^{(-k*t)} + Td_p$ (1)

$Td = IF(\ t<t_0,\ Td_0,\ Td_p + (Td_0 - Td_p)*\exp(^{-\ k*(t-t0)}))$ (2)

where Td is the turbidity as a function of time t, Td0 is the turbidity in the absence of polymer, Tdp is plateau turbidity, t is the time in seconds, and k is the interaction constant.

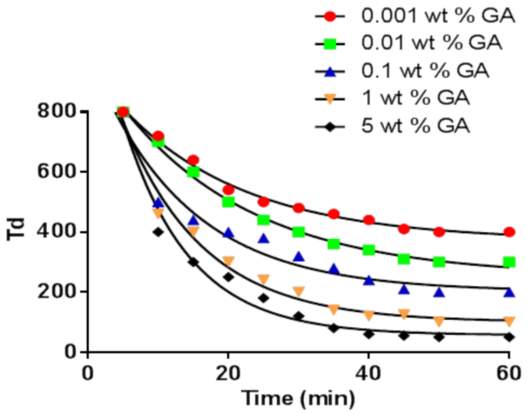

Figure 3. Kinetics plots for the interaction of silica suspension (10 wt%) with added GA at room temperature.

The reduction in turbidity with increasing the amount of GA polymer (Figure 3) implies that a low transmittance indicates that the sample contains suspended particles, which have scattered the majority of the light that entered it. Those samples will exhibit a definite cloudiness (opaque) and high turbidity (Turbidity = 100 – Transmittance %). By adding the polymer, the solution becomes clear. This indicates that there is an interaction between the GA functional groups and the SiO_2 molecules. As a result of this attraction, colloidal silica precipitates at the bottom of the solution, giving the appearance of a transparent solution. Figure 4 illustrates a mechanism of GA-SiO_2 interaction. This proposed mechanism is in perfect agreement with the fluorescence study of silica binding with polymers similar in composition to gum Arabic such as polyacrylic acid, alginate, and lipopolysaccharides[15-17].

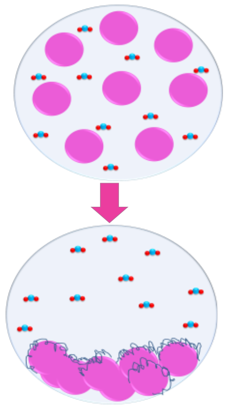

Figure 4. Turbid water suspended with silica turns clear when GA polymer is added (• silica particles and ~ GA polymer).

Table 1 lists interaction lifetime (τ) and its related parameters for GA-SiO_2 interaction, at 25 °C and pH 7. The interaction lifetime was determined using the turbidity technique, corresponding to the beginning of the plateau of interaction isotherm experiments. According to the R^2 values, the two-phase decay model was found to be the correct fit for the kinetic data at adding 0.001, 0.01, and 0.1 wt% of GA, while two-phase decay was a respectable fit at adding 1 and 5 wt% of GA. The interaction lifetime (τ) and its parameters were obtained by Graph Pad Prism® software.

Table 1. Graph Pad Prism Software® parameters for GA interaction with silica determined by turbidity (at 25 °C and pH 7):

wt% of GA	Fitting Parameters				
	Td_0	Td_p	τ/ min	k	R^2
0.001	955	372	17	0.05	0.99
0.01	984	251	18	0.05	0.99
0.1	1850	202	13	0.07	0.95
1	1133	100	11	0.08	0.98
5	1269	56	9	0.10	0.98

The results in Table 1 showed that the two-phase decay model describes well the experimental data at adding 0.001, 0.01, 0.1 wt% of GA, while the one-phase decay model was a good fit at 1 and 5 wt%, as they are corresponding R^2 value is considerably high (0.95 to 0.99). This means that turbidity values of silica suspension in the presence of GA are polymer concentration dependent. It was found that the Tdp, which represents the turbidity at the end of GA-SiO_2 interaction, of 372 NTU (at 0.001 wt% of GA) decays to 56 NTU as the quantity of polymer increases to 5 wt%. It is worth noting that the increase in the amount of interacted GA at higher concentration causes a decrease in interaction lifetime values from 17 min (at 0.001 wt% of GA) to 9 min (at 5 wt% of GA), followed by doubling the value of interaction constant as the amount of GA reached to 5 wt%. This proposes that at higher GA concentrations there is a complete interaction of $-CH_2COOH$ groups on SiO_2 particles, which could be via hydrogen bonding, that is confirmed by the one-phase model. At lower GA wt%, some silica particles remain in the bulk solution, therefore the two-phase model was necessary to simulate both reacted and unreacted SiO_2 particles.

Since the experiment of treating artificially turbid water proved that the GA polymer was a good water clearer, the purification efficiency of GA polymer was then examined by investigating the physicochemical properties of groundwater samples gathered from three diverse wheels in Benghazi (Libya), which were named as S1, S2, and S3, respectively. Tables 2-4 show the mean values of all measured physicochemical parameters corresponding to S1, S2 and S3 samples before and after treatment with 1 and 5 wt% of GA. A considerable reduction was recorded in the mean values of turbidity; Td, total dissolved solids; TDS, total alkalinity; TA, and total hardness; TH after treatment of S1, S2, and S3 samples with the natural polymer. Furthermore, the physicochemical parameters of all purified samples were in agreement with the World Health Organization (WHO) standards, especially when the samples were treated with 5 wt% of GA.

Table. 2 The mean values of the physicochemical parameters of groundwater samples before and after treatment with different concentrations of GA (S1 sample):

Parameter	Before GA Treatment	After Treatment With 1wt% GA	After Treatment with 5wt% GA	WHO value
Td /NTU	10±0.04	7±0.02	6±0.03	5
TDS /ppm	640±0.2	622±0.1	504±0.2	500
TA/ppm	300±0.6	260±0.4	202±0.2	200
TH/ppm	680±0.9	620±0.8	480±0.4	500

Table. 3 The mean values of the physicochemical parameters of groundwater samples before and after treatment with different concentrations of GA (S2 sample):

Parameter	Before GA Treatment	After Treatment With 1wt% GA	After Treatment with 5wt% GA	WHO value
Td /NTU	9±0.01	8±0.04	7±0.06	5
TDS /ppm	630±0.3	611±0.4	505±0.2	500
TA/ppm	280±0.6	210±0.4	190±0.5	200
TH/ppm	639±0.8	600±0.3	488±0.7	500

Table. 4 The mean values of the physicochemical parameters of groundwater samples before and after treatment with different concentrations of GA (S3 sample):

Parameter	Before GA Treatment	After treatment With 1wt% GA	After treatment with 5wt% GA	WHO value
Td /NTU	7±0.01	6±0.02	5±0.01	5
TDS /ppm	600±0.2	580±0.3	501±0.4	500
TA/ppm	278±0.5	218±0.3	198±0.9	200
TH/ppm	622±0.2	577±0.6	444±0.4	500

When water samples from three different wheels were treated with 1 and 5 wt% of GA (Tables 2-4), it was found that a higher amount of polymer resulted in a higher level of reduction in the mean values of physicochemical parameters (Td, TDS, TA, TH). In the comparison of values for the various parameters, there was a definite difference between treated and untreated water samples. According to analysis, treated water samples had turbidity, total dissolved solids, total alkalinity, and total hardness values that were 30, 20, 31, and 27% lower than untreated water samples (S1, S2, and S3). This reduction could be attributed to the interactions of GA functional groups with monovalent salts and divalent salts with respect to different anions and cations which could be present in natural water [18], which in turn led to the precipitate of those salts from bulk water. That attribution was also in agreement with our previous work on a polysaccharide that has a similar structure to GA[19]. This study looked at how salts affected the bulk and interfacial properties of starch using a combination of UV spectroscopy and turbidity methods. Significant variations in turbidity values were found when starch interaction with monovalent, divalent, and trivalent cations was studied (Td). The charge of the interacting cations has a considerable impact on Td, according to an interpretation of the obtained results. However, the Td values were significantly reduced by adding additional halide salt (NaX) as a result of the direct interaction between the X- ions and hydrogen in the hydroxyl group of starches. The majority of the physicochemical characteristics were, according to the analysis, within the World Health Organization's guidelines for drinking water quality following treatment [2]. It is clear that GA polymer could be utilized to effectively purify ground waters as a powerful natural coagulant.

4. CONCLUSION

This work has demonstrated that 5 wt % of gum Arabic polymer can significantly interact with salts and silica to filter turbid water. The water collected from various wells was also successfully reduced in turbidity, total dissolved solids, total alkalinity, and total hardness. It may be possible to use this economical and ecologically friendly method of water treatment to provide safe and drinkable water.

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