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Removal of hardness from groundwater via electro-coagulation method

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Abstract :

Groundwater makes up an important part of global freshwater resources, though it is often threatened by over use of natural resources along with abundant production of wastes in modern society. This study aims to investigate the removal hardness with the impact of this process on two major groundwater parameters, namely TH, TDS (Total Dissolved Solid) and EC at a laboratory scale. The experiments have been performed using four cast iron electrodes ,two electrode as cathode and two electrode as anode . Physical and chemical tests were done on the water of the well. The results achieved showed their values have exceeded the limits of Iraqi description and WHO for drinking water. The treatments include done three pH ranges (5,7and9) and treatment direct on raw water. The treatment method consists of three steps: electrocoagulation, oxidation of ferrous hydroxide to ferric hydroxide (which will partially convert to polymer from this compound) by air current for an hour, and adsorption by $Fe(OH)_2$ and $Fe(OH)_3$. The best removal effectiveness of this approach was found at pH 9 of TH 66%, TDS 21%, and EC 18%, according to the results.

Key words: Total hardness . Electrocoagulation . Groundwater. Iron electrodes.

ازالة العسرة الكلية من المياه الجوفية بطريقة التخثير الكهربائي

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مستخلص

تشكل المياه الجوفية جزءاً هاماً من موارد المياه العذبة العالمية ، على الرغم من أنها غالبا ما تكون مهددة لكثرة استخدامها كمصدر طبيعي إلى جانب إنتاج النفايات بكثرة في المجتمع الحديث. تهدف هذه الدراسة إلى تقييم عملية ازالة العسرة الكلية مؤشرين رئيسيين هما التوصيلية الكهربائية والاملاح الذائبة في المختبر .تضمنت التجربة استخدام اربعة الوا من حديد الزهر اثنان كقطب كاثود واثنان كقطب انود. اجريت الاختبارات الفيزيائية والكيميائية على مياه البئر. وأظهرت النتائج التي تم الحصول عليها أن قيمها تجاوزت حدود المواصفة العراقية ومنظمة الصحة العالمية لمياه الشرب. تضمنت المعالجة إجراء ثلاث مديات من الأس الهيدروجيني (5،7, 9) والمعالجة المباشرة بثلاث مراحل بطريقة التخثير الكهربائي وهي اكسدة الحديد عند قطب الانود وتحرره الى المحلول المائي بشكل ايون حديدوز وتكون هيدروكسيد الحديدوز الذي يتاكسد جزء منه بواسطة التهوية لمدة ساعة الى هيدروكسيد الحديديك ويتكون بشكل بوليمر الذي يحصل عليه الامتزاز. بينت نتائج المعالجة ان افضل كفاءة ازالة للعسرة الكلية والاملاح الذائبة والتوصيلية الكهربائية كانت عند اس هيدروجيني 9 (21%,66% و18%) على التوالي طبقا للنتائج.

الكلمات المفتاحية: عسرة كلية ، تخثر كهربائي ، مياه جوفية ، اقطاب حديد .

1- Groundwater

One of the main water sources is groundwater, which is impacted by both natural and man-made influences. The problem of groundwater resource quality has grown in importance in tandem with the rise in groundwater use[1]. Point source pollution has received a lot of attention in the past several years. The general quality of groundwater resources and nonpoint sources of pollution have become more of a cause of concern in recent times [2].Groundwater is recognized as one of the planet's most essential, renewable, and widely dispersed resources. It also serves as a major global source of water supply. Because groundwater is the primary source of clean drinking water, the majority of people rely on it.[2]. As one of the most valuable resources and essential to human existence, groundwater not only meets human needs but also gives humans the luxury and comforts they enjoy, but it also plays a crucial role in the development of our eco-system by fostering industrial and agricultural growth [3].

An rising hazard to groundwater has emerged in recent years Pollution from organic (volatile organic compounds, pesticides, xenobiotics), inorganic (heavy metals, hardness, nitrates/nitrites, sulphate), or a mix of organic and inorganic pollutants is a serious global health hazard. The growing use of chemical substances (such as pesticides and fertilizers) as well as unregulated wastewater discharges are to blame for this widespread groundwater contamination. One of the most common contaminants in groundwater, nitrate is linked to a number of illnesses, such as thyroid disorders, malignancies, and methemoglobinemia, or "blue baby syndrome." Because of human activity, nitrate levels in groundwater have become more important [4]. Man's activities at the ground surface, whether purposefully through household, industrial, and agricultural effluents or inadvertently through the subsurface or surface dumping of sewage and industrial wastes, have a negative impact on the quality of groundwater [5,6].

1-2 Electrocoagulation

Numerous water impurities have been eliminated by the use of electrocoagulation as a treatment method. Among its benefits are process adaptability, sludge reduction, low operator attention requirements, and simplicity of use[7]. The capacity of water particles to react in a redox reaction to a high electric field is what drives the main mechanism of electrocoagulation. Its broad application allows it to be utilised for groundwater and surface water remediation at various locations. It is particularly successful in eliminating inorganic pollutants and pathogens from a variety of water and wastewater treatment systems. It employs highly charged polymeric metal hydroxide species to remove metals, soluble inorganic contaminants, and colloidal solids and particles from aqueous systems. To aid in coagulation or agglomeration, these species balance the electrostatic charges on oil droplets and suspended particles[8]. By electrically dissolving iron or aluminium ions from corresponding iron or aluminium electrodes, coagulants are created in situ. At the anode, metal ions are generated, while at the cathode, hydrogen gas is liberated. The flocculated particles would be assisted in floating out of the water by the hydrogen gas. Electro flocculation is another name for this procedure. Figure (1) depicts it schematically. There are two conceivable electrode configurations: monopolar and bi-polar. The materials might be packaged as scraps like millings and steel turnings, or they can be aluminium or iron in plate form. The following are the chemical processes that are occurring at the anode.For aluminum anode:

$$AL \rightarrow 3e - + AL3 + \qquad (1)$$

at alkaline conditions

$$AL3 + + 3OH - \rightarrow A(OH)3 \qquad (2)$$

at acidic conditions

$$AL3 + + 3H20 \rightarrow AL(OH)3 + 3H + \qquad (3)$$

For iron anode:

$$Fe \rightarrow 2e - + Fe2 + \qquad (4)$$

at alkaline conditions

$$Fe2 + + 3OH - \rightarrow Fe(OH)2 \qquad (5)$$

at acidic conditions

$$4Fe2 + + 02 + 2H20 \rightarrow 4Fe3 + + 4OH - \qquad (6)$$

In addition, there is oxygen evolution reaction at the anode

$$2H20 \rightarrow 02 + 4H + + 4e - . \qquad (7)$$

The reaction at the cathode is

$$2H20 + 2e \rightarrow H2 + 20H - . \qquad (8)$$

The nascent Al^{3+} or Fe^{2+} ions are very efficient coagulants for particulates flocculating. Al^{3+} ions on hydrolysis may generate $Al(H_2O)_6^{3+}$, $Al(H_2O)_5OH^{2+}$, $Al(H_2O)_4(OH)^{2+}$ and the hydrolysis products may form many monomeric and polymeric species such as $Al(OH)^{2+}$ (aq),$Al(OH)_2^{+}$(aq),$Al_2(OH)_2^{4+}$ (aq), $Al(OH)_4^{-}$ (aq), and polymeric species such as $Al_6(OH)_{15}^{3+}$ (aq), $Al_7(OH)_{17}^{4+}$

(aq), $Al_8(OH)_{20}^{4+}$ (aq), which finally transform into $Al(OH)_3(s)$ according to complex precipitation kinetics[9]. For Fe anode some metallic complexes are: $Fe(OH)_3$, $Fe(OH)_2$, $Fe(OH)^{2+}$, $Fe(OH)_2^+$, $Fe(H_2O)_4(OH)^{2+}$, $Fe(H_2O)_5(OH)^{2+}$, $Fe_2(H_2O)_6(OH)_4^{2+}$, $Fe(OH)_4^-$, $Fe(H_2O)_6^{3+}$, $Fe_2(H_2O)_8(OH)_2^{4+}$, which finally transform into $Fe(OH)_2(s)$ and $Fe(OH)_3(s)$ [9].

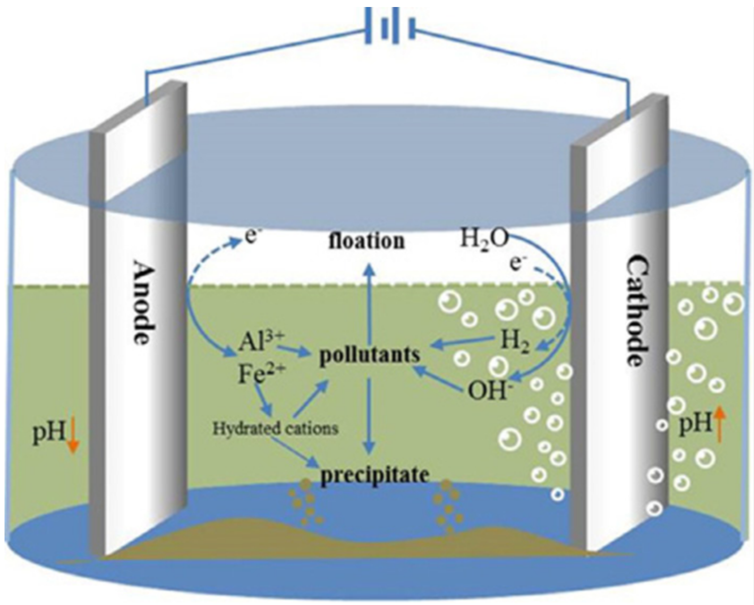

Figure 1 Electrocoagulation Arrangement

2- Materials and methods

2-1 Electrocoagulation Arrangement

An electrical setup is created using a power source to provide the DC needed for treatment and iron plates made solely of carbon and iron that were chopped into pieces measuring 15 by 10 cm. There were four plates available—two for the cathode, two for the anode, and a two-liter beaker. By adjusting with HCl and NaOH solutions, well water with varying salt concentrations and pH values of 5, 7, and 9 was created. A magnetic stirrer was used to agitate 1.5 litres of well water in a beaker. Two plates each were gathered for the anode and cathode. To oxidise Fe to Fe^{2+} ions, a voltage of 18 volts and a current of 3 amps was applied to the plates. Water is electrolyzed at a cathode to produce OH- ions and H_2 gas. Ferrous hydroxide is created when the OH-ion and Fe^{2+} combine. Ferrous hydroxide was oxidised to ferric hydroxide, which will then be converted to polymer, using an air current for an hour. So that adsorption of well waters ions is adsorbed on this compound.

3- Result and dissection

For every applied well, the electrocoagulation treatment results showed a general rise in the proportion of turbidity on a ferric hydroxide piece (precipitation of suspenders on the pieces of ferric hydroxide). All three treatments resulted in a rise in pH, with the exception of pH 9.Due to the full oxidation of Fe(OH)2 into Fe(OH)3, which precipitates as brownish precipitation, pH values following treatments at pH 9 are less than 9. Following treatment, the well's EC values decreased, and a drop in the concentration of dissolved salts was suggested as the cause. Using electrocoagulation, the greatest reduction of EC at pH 9 in all treatments resulted in a drop in dissolved salts. Uncertainties in the dissolved oxygen levels in well fluids following electrocoagulation therapy.The water's electrolysis, hydrogen emissions, OH- formation, and air aeration to promote the oxidation of $Fe(OH)_2$ to $Fe(OH)_3$ were the causes of these uncertainties. The first method's treatment, which involved electrocoagulation, increased the removal process in high pH because a higher pH causes an increase in OH- ions, which in turn causes an increase in ferric hydroxide pieces. This increased ferric hydroxide piece content improved the material's ability to adsorb Ca^{2+} and Mg^{2+} in high basic medium.At pH9, a higher proportion of Ca^{2+} and Mg^{2+} elimination produced better results[(10)]. Because $Fe(OH)_3$ is formed when Ca^{2+} and Mg^{2+} are adsorbed, the removal efficiency increases with pH. For electrocoagulation, pH 9 is the ideal pH value. A higher pH will result in more hydroxyl ions, which then produce Fe $(OH)_3$, which can adsorb contaminants and lower COD. Acidic and alkaline environments resulted in a reduction in the COD removal efficiency. The distribution of iron ionic species explains this outcome. The species are helpful in eliminating stable and insoluble contaminants. The species of Fe^{3+} Fe(OH)2+ Fe(OH)2+ ions are prevalent in acidic circumstances, whereas the species of Fe(OH)4 ions are dominant in alkaline situations. These species are soluble, and the solubility of Fe(OH)3(S) rises; nevertheless, these species are ineffective for removing COD. Fe(OH)3(S) is stable, insoluble, and accessible for pollutant adsorption from wastewater at a pH of neutral. Fe(OH)3(S) is therefore crucial to the elimination of COD. The HCO_3^- findings decline when pH5 electrocoagulation is used as a therapy.However, a drop in bicarbonate was seen at pH7 due to a significant conversion of HCO_3^- to $CO3^{2-}$.The concentration of HCO_3^- (zero) at pH9, which results from the pH dropping during treatment and airing. In every pH instance, the activated carbon treatment resulted in a greater removal efficiency. Electrocoagulation treatment results in a more effective F- elimination at pH 7. Fe(OH)4-is produced when pH>9.5, whereas Fe^{2+} is released at the cathode. Fe(OH)3 is created, and this adsorbs the F-ion. The removal of fluoride ion is best at neutral conditions (pH=7) is better than basic conditions [11] . The results of SO_4^{-2} ion removal showed limited removal at all pH ,but the best removal at pH5 [12]. The elimination of nitrate ions was demonstrated by a rise in $Fe(OH)_3$ production, which adsorbs NO_3^-, or by a process involving hydroxide ions and metal.When electrocoagulation using the first approach was present, the optimal elimination occurred at pH 9.The effect of pH and desorption studies demonstrate that chemisorption and ion exchange mechanism are operational in the adsorption process; adsorption is not possible by ion exchange mechanism but only by chemisorption surface complex formation of nitrate with the surface adsorbent [13]. The pH of the solution has a significant impact on the adsorption of nitrate ions. When pH increased, there was an increase in silica removal. The initial technique using activated carbon at pH 7 produced the greatest removal.

Table (1) showed the efficiency before and after treatment by use electrocoagulation

Parameter	Raw	pH5	Efficiency %	Raw	pH7	Efficiency %	Raw	pH9	Efficiency %	WHO 2011	IQS 2009
Temp	27	39		27	44		27	40			
Turb	0.4	3		0.4	2.5		0.4	2.8		-	-
pH	5	7.4		7	8.1		9	8.2		6.5-8.5	6.5-8.5
E.C	3410	3204	6	3360	3125	7	3310	2718	18	1000	1500
TDS	2430	2115	13	2310	1988	14	2360	1855	21	1000	1000
TSS	2	3		2	3		2	3			
D.O	11.	11. 2		11.	10.		11	9.6		10>	10>
COD	14	0	100	14	0	100	14	0	100	10>	10>
TH	933	610	35	933	508	46	933	320	66	500	500
Ca^{2+}	210	140	33	210	128	39	210	55	73	75	150
Mg^{2+}	105	66	37	105	52	50	105	48	54	50	100
Na^{+}	365	318	-	365	332	-	397	358	-	200	200
K+	28	23	-	28	24	-	28	19	-	10	-
F^{-}	3.9	1.2	69	3.9	1	74	3.9	1.1	71	1	1
HCO_3^-	97	21	-	0	0	-	0	61	-	500	200
Cl^{-}	873	833	-	795	726	-	756	716	-	250	350
SO_4^{2-}	613	438	28	613	452	26	613	501	18	250	400
NO_3^-	144	108	25	144	89	38	144	78	45	50	50
SiO_2	21.1	15.2	28	21.7	9.7	54	21.7	10.1	51	5	5

4- Conclusion

In order to lower the overall hardness of the well water, the study used electrocoagulation using four cast iron plates—two for the cathode and two for the anode. In order to investigate the impact of current density three amperes for one hour, batch electrocoagulation experiments were conducted utilising an iron electrode configuration as the anode and cathode. Due to the adsorption of calcium and magnesium ions on the surface of the ferrous hydroxide and the precipitation of calcium and magnesium ions also in the hydroxide form of these ions, along with the decrease in the value of electrical conductivity and total salts, the treatment results demonstrated good total hardness removal efficiency at a pH of 9.

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