



Evaluation of electrocoagulation for the pre-treatment of coal seam water



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ABSTRACT

This work explored the applicability of electrocoagulation (EC) using aluminium electrodes for the removal of contaminants which can scale and foul reverse osmosis membranes from a coal seam (CS) water sample, predominantly comprising sodium chloride, and sodium bicarbonate. In general, the removal efficiency of species responsible for scaling and fouling was enhanced by increasing the applied current density/voltage and contact times (30–60 s) in the EC chamber. High removal efficiencies of species potentially responsible for scale formation in reverse osmosis units such as calcium (100%), magnesium (87.9%), strontium (99.3%), barium (100%) and silicates (98.3%) were achieved. Boron was more difficult to eliminate (13.3%) and this was postulated to be due to the elevated solution pH. Similarly, fluoride removal from solution (44%) was also inhibited by the presence of hydroxide ions in the pH range 9–10. Analysis of produced flocs suggested the dominant presence of relatively amorphous boehmite (AlOOH), albeit the formation of Al(OH)₃ was not ruled out as the drying process employed may have converted aluminium hydroxide to aluminium oxyhydroxide species. Evidence for adsorption of contaminants on floc surface sites was determined from FTIR studies. The quantity of aluminium released during the electrocoagulation process was higher than the Faradaic amount which suggested that the high salt concentrations in the coal seam water had chemically reacted with the aluminium electrodes.

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1. Introduction

The coal seam gas (CSG) industry represents an important segment of the energy sector and of our future energy supplies [1,2]. Countries such as the USA, China and Australia are pursuing the extraction of CSG (known in some regions as coal bed methane (CBM)) which is trapped in coal cleats by water pressure [3]. A critical issue with respect to the development of the CSG industry is how to dispose, or reuse, the produced water which is typically contaminated with a range of dissolved species [4–6]. To this end, reverse osmosis (RO) has become an integral technology for the treatment of coal seam water [7,8]. However, it is well known that RO systems can suffer from fouling of the membranes [9–13]. Consequently, a range of approaches are required to clean the water prior to the final RO desalination stage [14].

Pre-treatment of coal seam (CS) water may offer the following benefits: (1) removal of particulate matter; (2) lowering of the

algal content (3) softening of water to decrease the concentration of calcium, magnesium, barium and strontium in order to inhibit scaling of equipment and (4) reduction of the presence of impurities such as iron, silica (colloidal and dissolved), bromide, boron, ammonium, nitrate, sulphate and fluoride which can either cause fouling problems, violate discharge limits or reduce the quality of the final brine generated by the RO unit. At present, there is no consensus on the best means to pre-treat coal seam water apart from a general stratagem to conduct filtration of large and small particles, and water softening [5,15]. To remove large particulate matter and algal impurities, the application of standard coagulation-flocculation technology and dissolved air flotation (DAF) may be viable options [16]. However, drawbacks to this approach include the use of significant volumes of coagulant, an inability to remove the majority of dissolved ions and slow, to very slow, rise rates in the final clarification stage due to the fine, colloidal nature of many formation products.

Electrocoagulation (EC) is a technique which has received interest in a wide range of water applications, summaries of which are provided in the literature [17–21]. Fundamental operating practices for EC involve the direct introduction of aluminium or iron coagulants to water by the application of an electric potential to a series of metal plates that are immersed in the water. It is claimed

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that EC offers several advantages compared to standard coagulation methods including: lower chemical addition; capability to treat a wide variety of water contaminants; ability to treat finer colloidal particles due to charge inactivation; smaller sludge volumes; low power consumption; small operating costs and reduced operational footprint [22,23]. Despite the aforementioned potential advantages of electrocoagulation, there appears to be minimal systematic evaluation of EC as applied to the treatment of coal seam water [24]. Rusdianasari et al. [25] evaluated electrocoagulation using aluminium electrodes for the remediation of coal stockpile wastewater. These authors found that removal of dissolved iron, manganese and suspended solids was promoted by increasing current density and exposure time. Sanfan [26] investigated the use of electrocoagulation to purify brackish water using a range of electrode types and configuration. Aluminium electrodes were said to be problematic in terms of cost and susceptibility to passivation and thus mild steel materials were favoured. Notably, it was reported that aeration of the incoming feed solution was required to ensure optimal performance. Reuse of flocs which settled to the bottom of the batch EC reactor was also postulated to be beneficial in terms of aiding removal of contaminants such as alkaline earth ions. Gomes et al. [27] applied electrocoagulation to produced water samples which contained a variety of dissolved metal impurities and were characterized by high chemical oxygen demand (COD). Significant control of the COD content was observed, albeit problems were encountered in terms of metal ion removal and this was attributed to a lack of “green rust” formation when using mild steel electrodes. Sanfan and Qinlai [28] reported a mechanistic investigation of brackish water purification using electrocoagulation and considered current density to be the most important factor. Koparal [29] demonstrated the applicability of electrocoagulation in conjunction with conventional water treatment methods such as precipitation, adsorption, filtration and electro dialysis for removal of salinity from produced water. Use of either mild steel or aluminium electrodes substantially reduced the concentration of all ions apart from sodium and chloride. The latter two species were removed when electrocoagulation was integrated with alternate desalination techniques.

The use of EC to treat CS water appears reasonable given that produced water inherently contains significant concentrations of sodium chloride. In early designs of EC processes, NaCl was added to solutions with low total dissolved solids (TDS) in order to make them conductive [30]. Hence, cost savings for EC operation are potentially available, as well as compatibility with EC operational practice, in the treatment of coal seam water [31]. This study therefore reports the outcomes of electrocoagulation using aluminium electrodes to treat actual coal seam water samples acquired from an operating coal seam gas field in Queensland, Australia.

2. Experimental

2.1. Electrocoagulation

The EC system originally supplied by Ellers Water Services Australia was based on the technology of Powell Water Recovery [32,33]. The basic set-up comprised a vertical cell which accommodated 13 electrode plates of dimension 15 by 10 by 0.3 cm, separated by a distance of 0.3 cm [Fig. 1]. In this work, aluminium electrodes which had been previously cleaned by exposure to a 30% (v/v) hydrochloric acid solution, were evaluated for their performance. The EC system was operated in a bipolar arrangement [34] and subjected to polarity reversal approximately every 30 s. All experiments were conducted at an ambient temperature of ca. 22 °C.

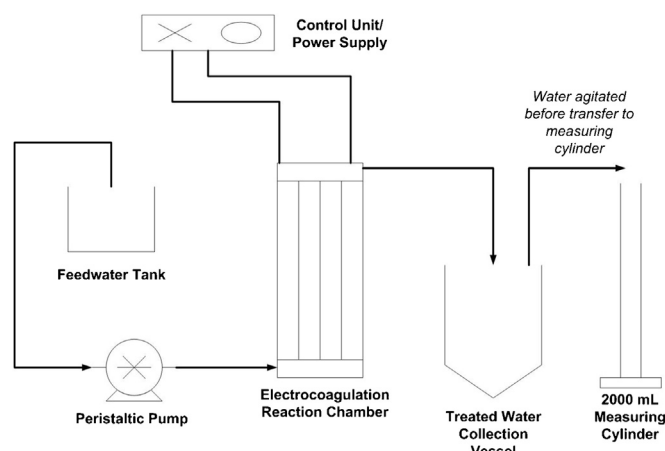


Fig. 1. Schematic of laboratory scale set-up for electrocoagulation trials.

2.2. Analysis methods

2.2.1. Inductively coupled plasma optimal emission spectrometer (ICP-OES)

A PerkinElmer Optima 8300 DV ICP-OES was used to analyze aqueous samples. Prior to analysis, samples were adjusted to pH = 2 by addition of 100 μ L of 70% nitric acid which was first purified using a Savillex DST-1000 distillation unit. Ca, Mg, Na, Fe and K standards were prepared by using Australian Chemical Reagents (ACR) multi-element standard, while boron, Si and Al standards were prepared separately using ACR single element standards.

2.2.2. Ion chromatography

A Dionex 2100 – RFIC ion chromatography unit was used to analyze a range of anions in aqueous solution. The samples were filtered through a Dionex OnGuard II Na column to remove Al. The standards were prepared from AR grade sodium and potassium salts dried in an oven for 2 h at 150 °C. The method of analysis conformed to EPA method 300.1. The software package, Chromeleon was used to control instrument conditions and process data. A Dionex AS 18 (4 mm \times 250 mm) column was heated at 30 °C and a conductivity detector was heated at 35 °C with 25 μ L injection.

2.2.3. pH and conductivity

Solution pH and conductivity measurements were undertaken with meters supplied by TPS, Australia. The pH meter was calibrated using pH buffer 7.00 and 4.01 standard solutions manufactured by TPS, while the conductivity meter was calibrated in air and a 2.76 mS conductivity standard supplied by TPS.

2.2.4. Total organic carbon (TOC)/dissolved organic carbon (DOC)

A GE Sievers InnovOX TOC analyser fitted with a GE autosampler was used to analyze TOC/DOC in all the samples in this study. The DOC samples were first filtered through a 0.45 μ m syringe prior to the analysis, whereas the TOC samples were taken directly from each experimental water sample.

2.2.5. Total suspended solids (TSS)

Advantec GB-140 glass filter paper was used for all the TSS measurements. The aqueous sample was first filtered through the filter paper and then dried in an oven at 120 °C for at least an hour. The sample was then removed from the oven and allowed to cool before being accurately weighed. It was then put back in the oven to dry for another hour until the difference in the consecutive weight values was no more than 0.5 mg.

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