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Transient response of microbial communities in a water well field to application of an impressed current

P.G. Medihala [a], J.R. Lawrence [b], G.D.W. Swerhone [b], D.R. Korber [a,*]

[a] Department of Food and Bioproduct Sciences, University of Saskatchewan, 51 Campus Drive, Saskatoon, SK S7N 5A8, Canada
[b] Environment Canada, Saskatoon, SK, Canada

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ABSTRACT

Deterioration of water wells due to clogging and corrosion over time is a common problem where solutions may be costly and ineffective. Pilot studies have suggested that impressed current or cathodic protection may be used to reduce microbially-induced declines in water well performance. Two water wells in an alluvial aquifer close to the North Saskatchewan River were selected to study the response of subsurface microbial communities to the application of an impressed current as an anti-fouling technology. The treated well was exposed to an impressed current while the untreated well was used as a reference site. Biofilms grown on *in situ* coupons under the influence of the impressed current were significantly ($p < 0.05$) thicker (mean thickness = 67.3 μm) when compared to the biofilms (mean thickness = 19.3 μm) grown outside the electric field. Quantitative PCR analyses showed significantly ($p < 0.05$) higher numbers of total bacteria, iron- and nitrate-reducers in the electrified zone. Molecular analysis revealed that the predominant bacteria present in biofilms grown under the influence of the impressed current belonged to *Rhodobacter* spp., *Sediminibacterium* spp. and *Geobacter* spp. In addition to favouring the growth of biofilms, direct microscopic and ICP-AES analyses revealed that the impressed current also caused the deposition of iron and manganese on, and in the vicinity of, the well screen. Together, these factors contributed to rapid clogging leading to reduced specific pumping capacities of the treated well. The study revealed that the impressed current system was not effective as an anti-fouling technology but actually promoted both microbial growth and physical clogging in this aquifer.

1. Introduction

Water is vital for all forms of life on earth and about 96% of earth's renewable fresh water is comprised of groundwater. Canada's population (30.3%) makes extensive use of groundwater for domestic, agricultural and industrial purposes (www.ec.gc.ca/eau-water). Approximately 43% of all agricultural needs are supplied by groundwater, accounting for 34% of water wells in Canada (Nowlan, 2005). Groundwater can be a reliable source of high quality water and to ensure its adequate supply throughout the year, long-term water well performance is important. However, water wells can be susceptible to clogging and corrosion over time, often due to improper maintenance or operations, leading to declines in water quality and yield. Our lack of understanding of the factors responsible for these problems may result in the application of expensive, ineffective and inappropriate rehabilitative and preventive measures (Cullimore, 2000).

Biofouling is a process of deterioration caused by biological activity. Biofouling in wells and aquifers mainly refers to the

* Corresponding author. Tel.: +1 306 966 7786; fax: +1 306 966 8898.
E-mail addresses: darren.korber@usask.ca, drprabhakaramg@gmail.com (D.R. Korber).
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processes of clogging and corrosion (Howsam, 1988). Well clogging usually occurs at either the well screen slots or the well bore (van Beek, 1989). Well clogging, if not addressed, can lead to loss of production capacity, reduced water quality and can interfere with reliable delivery of water (van Beek, 1989; Cullimore, 2000; van Beek et al., 2009). Well rehabilitation and biofilm control methods may be employed when there is evidence of significant biofouling in conjunction with declines in well performance (Howsam, 1988; ESTCP, 2005). Rehabilitation commonly involves physical or mechanical disruption methods coupled with chemical treatment(s) (Basso et al., 2005). Although mechanical procedures like swabbing, jetting, brushing, surging and forced pumping can temporarily restore well performance, optimal results are obtained when these physical methods are combined with chemical treatments that may include strong oxidizing agents (chlorine) and acids (e.g., muriatic or glycolic acids) which dissolves iron and other oxides and may also mediate biomass detachment (van Beek, 1989; Taylor et al., 1997; Basso et al., 2005; ESTCP, 2005). Alternatively, biofouling controls and preventative measures may be employed to reduce, inhibit or prevent bacterial populations from forming biofilms, hence minimizing or eliminating the need for well rehabilitation in the first place (van Beek et al., 2009). Many innovative biofouling prevention approaches have been proposed; for example, biological treatment of clogged wells using lytic phages to reduce biofouling bacteria has been attempted and shown to be successful in a lab-based study conducted by Gino et al. (2010). A review on various rehabilitation and biofouling control methods can be found in ESTCP (2005).

Various studies have been conducted in the field of medical biofouling, documenting the influence of electric fields on the modification of biofilm structure, detachment and viability. These studies have mainly focused on increasing the efficacy of antibiotics against disease-causing biofilm bacteria by a mechanism termed the "bioelectric effect" (Costerton et al., 1994) whereby an alternating-phase DC current enhances the penetration of charged antibiotics into the biofilm matrix. In addition, prolonged exposure to low-intensity electric current alone has been shown to substantially decrease the viability of bacterial biofilms grown on Teflon coupons, a phenomenon termed an "electricidal effect" (del Pozo et al., 2009). Studies have also demonstrated that bacterial biofilm detachment from metallic surfaces could be stimulated when a small direct current (DC) was applied (van der Borden et al., 2004).

In agricultural, municipal and industrial applications, impressed current is frequently used in cathodic systems to protect subsurface metal pipelines from corrosion. A typical system employs an external direct current (DC) source (rectified) to impress a current from an external inert anode on to a cathodic surface where the cathode is the metal to be protected from corrosion (Bushman, 2001; SESCO, 2002). Cathodic protection is based on an electro-chemical principle involving electro-migration and electrophoresis (Gulck, 2005). Globa and Rohde (2003) made an attempt to mitigate water well clogging by using an impressed current cathodic protection system. Their results suggested that impressed electric current could control the reduction of pore clogging in a laboratory-based model well. Since a control well was not used in their study, it was difficult to assess whether impressed current was effective in mitigating well clogging.

Established water wells in an aquifer in The City of North Battleford, located on the North Saskatchewan River in Saskatchewan, Canada, have typically undergone rapid deterioration in both well yield and water quality, often with losses of up to 50% of capacity within 5 years. These losses have resulted in the need for expensive and potentially unsustainable short-term rehabilitative measures that have included surging, surfactants, and acid–base treatments. The objective of the present research was to study the response of the subsurface microbial communities to the application of an impressed current and evaluate its performance as a preventative technique to mitigate or prevent well biofouling. Such an approach would help in developing an improved and cost-effective biofouling control strategy that could be applied to problem water wells and would directly benefit the long-term performance of water wells and water quality issues in domestic, industrial and agricultural sectors.

2. Materials and methods

2.1. Study location and well installation

The water well capture zone site is situated at the western end of The City of North Battleford's well field (SE ¼-12-44-17-W3 and NE ¼-1-44-17-W3) (Fig. 1). The aquifer is unconfined in alluvial sand and silt, consisting of fluvial deposits of reworked sand and incorporated organic matter adjacent to the North Saskatchewan River. Two 20 m deep research production wells, a control well (CW) and electrified well (EW), were installed approximately 60 m apart, each with a 6 m screened length at the bottom. The wells were operated continuously at an approximately 90 igpm (Imperial gallons per minute) pumping rate in parallel with the existing production wells in the well field. Piezometers (2 inch Internal Diameter PVC pipe) with a screened section at the bottom (similar to the production wells) were installed around the production wells for sample collection, with piezometers were categorized as being either in zones approximately 1 m or 5 m from the well (Fig. 1), with two piezometers each – one for water collection and the other for biofilm incubation.

2.2. Installation of the impressed current system

The impressed current system consisted of four anode strings attached to PVC piezometers installed at 1.5 m radial distance from the EW. Each anode string consisted of five 1.2 m long, mixed-metal oxide anodes installed to a depth of 18 m and corresponding to the entire length of the screened section of EW. A rectifier was used to apply direct current from the anode towards the metal well screen (cathode). The layout of the impressed current system is shown in Fig. 2. Application of the impressed current system started in June 2007, and was removed ~5 months later in October. The rectifier was set to deliver 58.5 V and 10 amps current, based on previous field trials. Rectifier readings taken over the course of four months showed a gradual decline in voltage from 58.5 to 28.5 V; however, the current flow was maintained over the same period at 10 amps.