////Title: Monitoring Corrosion in Aquifer Thermal Storage Systems

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Corrosion and scaling processes in water heating and cooling systems can create the need for hugely costly repairs. Until now, however, techniques to monitor the extent of the damage they inflict have been severely limited. In a 2013 study, Dr Oliver Opel and his colleagues at Leuphana University of Luenburg in Germany made significant strides towards tackling the issue by devising a method to accurately monitor corrosion and scaling in a large aquifer thermal storage system. Their technique was based on an easily determinable value named the redox potential.

////Main text:

Many modern buildings in seasonal climates store the energy required for their heating and cooling systems in groundwater, present in systems of permeable rocks. During the summer, this water can be extracted, heated by excess heat from the building, before being injected back underground. In winter, the direction of flow is reversed, and the heat stored below the ground can be extracted.

These 'aquifer thermal storage' systems are environmentally friendly, since they can greatly reduce the energy requirements of the buildings they are connected to. However, a variety of inevitable chemical and biological processes also mean that their performance is vulnerable to deterioration over time.

This deterioration occurs since thermal aquifers can draw up a variety of ions and microbes from underground, which induce build-ups of minerals on pipe surfaces, pumps, and filters, through processes known as corrosion and scaling. These processes are strongly influenced by a variety of factors, including the pH of the water, its levels of dissolved oxygen, temperature, along with more complex chemical reactions. Microbes can also play a significant role, as they produce molecules containing sulphur, which can strongly contribute to corrosion.

With so many complex processes affecting the degrees of corrosion and scaling in thermal aquifer systems, sophisticated monitoring techniques are needed to maintain their functionality, and to reduce costs and downtimes.

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By 2013, a variety of technologies had been developed to monitor corrosion and scaling. Among them were biosensors, which consist of large colonies of microbes, adhered together by networks of polymers. Since these microbes can conduct electricity, electrodes placed at either end of the colony can pass a steady current across them. As corrosion plays out, the microbes become less effective conductors, meaning that corrosion can be directly linked to a decrease in current across the electrodes.

In addition, non-biological techniques including linear polarisation resistance and electrochemical sensors can measure changes in currents introduced across specialised solvents, again indicating corrosion.

Though effective, these techniques can only monitor small-scale corrosion processes directly at the electrode, giving little indication as to what is happening in the system as a whole. One potential solution to this issue is to measure the redox potential of the water in the system. The value of the redox potential describes the water's tendency to either gain electrons from the electrode, becoming reduced, or to lose electrons to the electrode, becoming oxidised.

This technique can monitor levels of corrosion and scaling across the entire system. However, its measurements are far less accurate than smaller-scale techniques, and little progress towards overcoming this problem has been made in the last 30 years.

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In a 2013 paper published in *Bioelectrochemistry*, Dr Oliver Opel and his colleagues at Leuphana University of Luenburg claimed that these problems existed because the models used to predict the chemical processes occurring in water during corrosion could not explain the measured changes in redox potential.

In their paper, the researchers suggested a more sophisticated approach – supplementing measurements of the redox potential with those of the pH, electrical conductivity, temperature, and levels of dissolved oxygen in the surrounding water. By establishing mathematical relationships between these values and the redox potential, the team could reliably correlate changes in its value with the progress of chemical reactions characteristic of corrosion in water heating and cooling systems.

With their updated technique, Dr Opel and his colleagues could measure the rates of oxidised iron build-ups on pipe surfaces as corrosion progresses. To do this, they simply assumed that this build-up rate was controlled by the solubility of molecules of iron hydroxide drawn up from underground aquifers – a value that could be directly calculated from the properties of the surrounding water.

Ultimately, this allowed them to use measurements of the redox potential to accurately monitor for corrosion in an entire system for the first time, provided that the measurements are supplemented with those of other easily determinable values.

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To demonstrate their technique, Dr Opel and his colleagues monitored for corrosion in the heating and cooling systems of two German parliament buildings in Berlin: the Reichstag and the Federal Chancellery. The energy demanded by the heating and cooling systems of both buildings is stored in a deep underground aquifer, making them vulnerable to corrosion induced by unwanted microbes and iron hydroxide molecules drawn up from underground. In their study, the team measured the redox potential of the aquifer water alongside its pH, conductivity, temperature, and dissolved oxygen.

Having monitored the system for ten years, Dr Opel's team concluded that lower redox potentials can be directly correlated with higher iron hydroxide build-up rates – themselves determinable by the other measured properties of the water. They also showed that microbes can strongly influence the redox potential by mediating 'sulphate-reducing' reactions, which produce molecules of hydrogen sulphide. Overall, the team's study gave a far clearer picture of corrosion processes in thermal aquifer systems than any other study had achieved previously.

For the first time, Dr Opel's study showed that measurements of the redox potential can indeed be useful for monitoring both microbe-induced and non-biological scaling and corrosion processes. The insights gathered by his team would allow property owners to improve the ways in which they plan out schemes for system maintenance, and to more accurately predict when repairs will be needed.

Finally, the study would provide a reliable basis for Dr Opel's future research at the West-Coast University of Applied Sciences, in which he investigated why the problem of corrosion appears to be getting worse in modern, more efficient heating and cooling systems.

Meet the Researcher

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