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Chromium, toxic or essential? Using the Erin Brockovich saga in chemistry teaching

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"Are we having a movie today?" is a popular refrain in classes. Current generations of students expect the visual stimulation common in their everyday experience. Here we will describe a documentary/movie combination that can add multiple discussion points to a chemistry class.

Many students are familiar with the Erin Brockovich saga through the movie "Erin Brockovich" starring Julia Roberts.[1] The movie is based on the true story of a leakage of chromate ion from the cooling towers of a natural gas pumping station owned by Pacific Gas and Electric (PG&E) into the groundwater of the town of Hinkley, California. A high proportion of residents experienced major health problems and it is widely believed that many were the result of ingestion of chromium(VI) compounds. Ms. Brockovich, a poor single mother with little education, was hired by a small legal firm as a 'go-fer' and file sorter. She became obsessed with the Hinkley case and, despite her lack of legal training, pursued it with total single-mindedness, intelligence, and dedication. The case went to court and the defendants settled for US $333 million. There are numerous websites on the case,[2] some with very partisan viewpoints.

Truth and fiction in movies

This article is timely in that a documentary video has recently been released, in August 2006. The video is an investigative program produced by the Arts & Entertainment Network (A&E) in the American Justice series, hosted by Bill Kurtis.[3]

The first discussion point is a comparison of the commercial movie with the documentary. The documentary itself notes some of the ways that the true story was 'tweaked' to improve the appeal to a cinema audience. However, one can argue that 'amending' the true story is a small price to pay for giving the problem of groundwater contamination such wide exposure.

The chemistry of chromate usage

First of all, we need to define what we mean by chromium(VI), which is given names in the non- and semi-scientific literature such as 'chrome 6' or 'hexavalent chromium.' Chromium does not exist as a free Cr^{6+} ion. It is usually available as salts of the yellow chromate ion, CrO_4^{2-}, or the orange dichromate ion, $Cr_2O_7^{2-}$. These two species are in a pH-dependent aqueous equilibrium:

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Chromium, *continued from page 1*

$$Cr_2O_7^{2-}(aq) + H_2O(l) \rightleftharpoons 2\,CrO_4^{2-}(aq) + 2\,H^+(aq)$$

At the high dilutions and in the typical pH range of groundwater, the chromate ion was probably the predominant contaminating species from the PG&E plant.

So why did PG&E use a solution of chromate ion? Chromate ion forms insoluble salts with many metal ions, particularly dipositive and tripositive ions. In water cooling systems, the presence of oxygen, dissolved salts, and warm temperatures promotes corrosion of metal surfaces. If chromate ion is present in the cooling liquid, most metal cations formed by oxidation, such as iron(III) ions, will react with the chromate ion:

$$2\,Fe^{3+}(aq) + 3\,CrO_4^{2-}(aq) \rightarrow Fe_2(CrO_4)_3(s)$$

These highly insoluble metal chromates form an impervious layer over the metal surface inhibiting further corrosion.

Another highly insoluble chromate is lead(II) chromate, the bright yellow compound traditionally used for yellow highway markings. Providing chromate ion is allowed in your school laboratory, you can demonstrate the formation of insoluble chromates. Two good examples are the precipitation of yellow barium chromate and of brick-red silver chromate.

$$Ba^{2+}(aq) + CrO_4^{2-}(aq) \rightarrow BaCrO_4(s)$$

$$2\,Ag^{+}(aq) + CrO_4^{2-}(aq) \rightarrow Ag_2CrO_4(s)$$

The toxicity of chromium(VI)

It has been established for some years that inhalation of chromium(VI) compounds (such as potassium or ammonium dichromate) as dusts causes tumour formation together with more immediate symptoms such as nosebleeds and ulcers.[4] Skin contact can cause skin ulcers or allergic reactions. It is the ingestion of chromium(VI) solutions where the evidence becomes murky. This, in itself, is an important point: human toxicity studies are difficult to perform and verify.

Some environmental health scientists contend that ingested chromium(VI) is largely reduced to innocuous chromium(III) in the saliva or stomach[4] while others argue that a significant proportion of the chromium(VI) survives the passage from the stomach into the blood stream.[5]

The key problem with chromium(VI) seems to be its absorption into cells. The tetrahedral chromate ion can use the same pathway into cells as the similar tetrahedral phosphate ion, PO_4^{3-}. To cite Lukanova et al[6]:

> Inside the cell, Cr(VI) is reduced to Cr(III), generating intermediate Cr(V) and Cr(IV) ions, oxygen, and organic radicals, causing DNA damage such as DNA strand breaks, Cr-DNA adducts, and DNA-protein cross-links, which have been shown to occur in vivo and in vitro.

Whether ingestion of chromium(VI) led to all the symptoms reported at Hinkley, is a matter for debate. However, there does seem to be substantial evidence that elevated levels of chromium(VI) in drinking water is a health hazard. The U.S. Environmental Protection Agency allows a maximum of 100 µg of total chromium per litre of drinking water while the Canadian[7] and Californian limit is 50 µg L^{-1}. The reason for citing total chromium is that any chromium(III) in water is oxidized to chromium(VI) by the chlorination process. However, it should be pointed out that setting some arbitrary, almost 'guess-timate,' limit doesn't mean that there is any specific safe level for all members of the population. Of note, the highest measured levels found in Hinkley were 580 µg L^{-1}.

The essentiality of chromium(III)

Having described the dangers of chromium in its +6 oxidation state, we will now point out that chromium in its +3 oxidation state is essential to human health! Thus students need to be aware the toxicity of an element is often very dependent on its oxidation state and environment. For example, mercury(II) oxide is comparatively innocuous, while mercury metal vapour is toxic by lung absorption, and dimethylmercury is extremely hazardous, being even skin-absorbed.[8]

Chromium(III) appears to be required for proper carbohydrate and lipid metabolism in mammals.[9] A normal diet, particularly one containing cereals and seafood, should provide sufficient chromium. However, a lack of chromium(III) has been shown to play a role in glucose intolerance, Type 2 diabetes mellitus (Type 2 DM), and gestational diabetes.[10] Administration of chromium(III) usually as the very water-soluble 'chromium picolinate' (chemical name, tris(picolinato)chromium, $Cr(C_6H_4NO_2)_3$), has been shown to alleviate the symptoms.

So, the next time you want to get your students interested in chemistry, show a movie!

References

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Su-chem-du with message

Here is another su-chem-du to challenge readers and their students. It has a wintry message in the first row like the December 2006 su-chem-du. Here is the clue — “three ways to find H_2O in the winter season.”

Everything else is the same as our usual su-chem-du. Each of the nine chemical symbols is to appear once in each row, column and each 3x3 square. At the bottom of the puzzle is the list of elements to be used. We’ll draw the winner of a periodic table from the correct entries on March 8, 2007. Send your entry to *Chem 13 News* su-chem-du January, Department of Chemistry, University of Waterloo, Waterloo ON N2L 3G1. Fax: 519-888-9168. E-mail: kjackson@uwaterloo.ca.

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