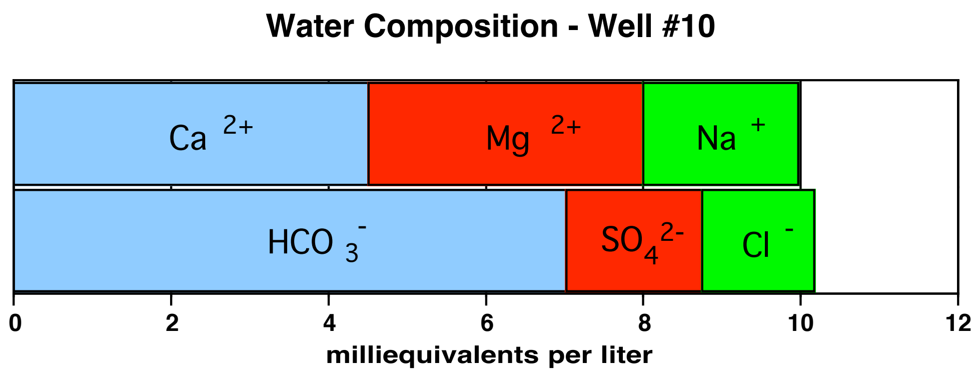
Introduction

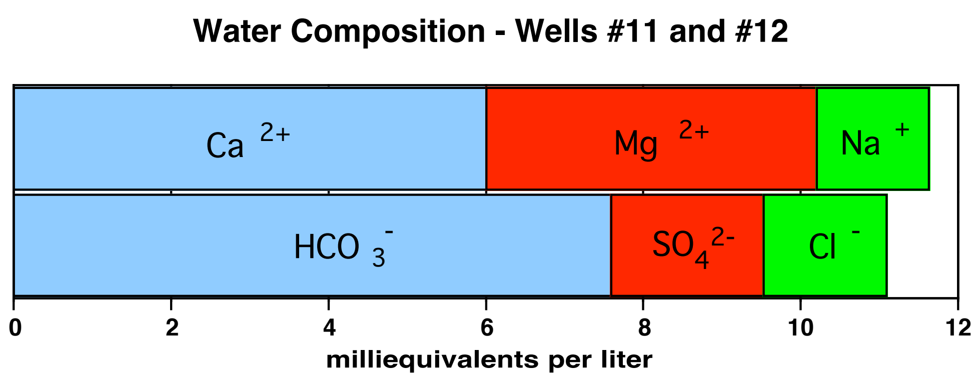
East Peoria's Oakwood Road Water Treatment Plant utilizes well water and provides aeration for ferrous iron oxidation. The aerated water is retained in a retention basin under the aerators to provide time for iron precipitation. Following the in-line addition of potassium permanganate to oxidize manganous ion, the aerated water enters dual media filter units where precipitated iron and manganese oxides are removed.

The current evaluation was undertaken November 18, 2002 as part of an investigation of the root causes of filter media encrustation. Following replacement of the original anthracite coal and sand filter media after only five years of service, filtration capacity has again progressively been lost over the past two years.

Well Water Influent to Oakwood Road Water Treatment Plant



Well #10 produces water that is hard (approximately 400 mg/l as $CaCO_3$ equivalent), but very low in iron and manganese (< 0.1 mg/l combined). This water also appears to be non-corrosive (neutral in pH) and has little tendency to deposit scale on the interior of distribution system piping or household plumbing. Accordingly, this water is pumped directly from the well to the distribution system without treatment except for chlorination.



Wells #11 and #12 serve as influent to the Oakwood Road Water Treatment Plant. While somewhat harder and higher in alkalinity, these well waters are similar in inorganic composition to the water from Well #10 except they contain noticeable amounts of iron and manganese. In these waters, ferrous ion has been measured in the range of 0.7 to 1.8 mg/l Fe while manganous ion averaged 0.23 mg/l Mn.

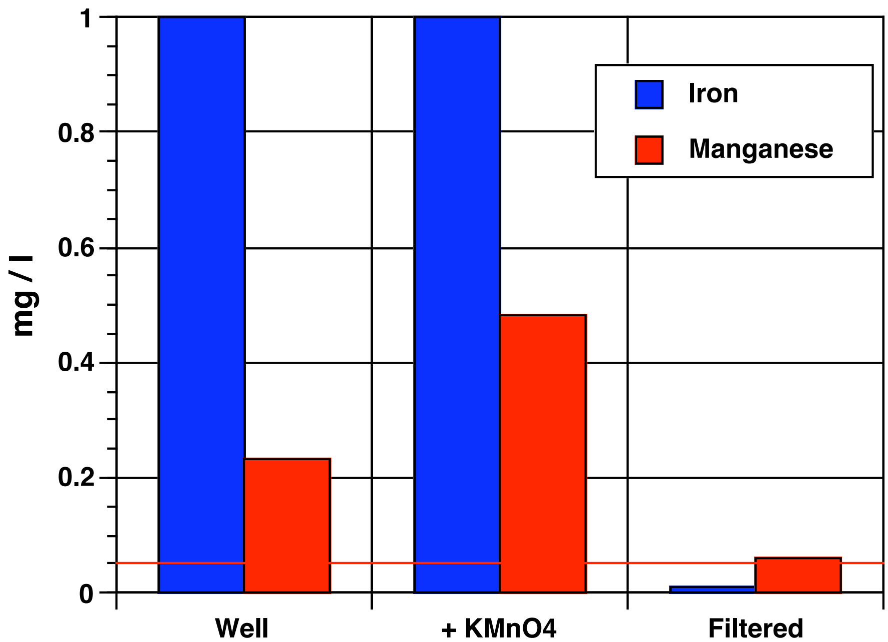
Well #	1993: mg/l Fe	1993: mg/l Mn	2002: mg/l Fe	2002: mg/l Mn
10	0.09	0.07	< 0.03	0.03
11	1.8	0.22	1.3	0.17
12	1.0	0.29	0.69	0.23

However, iron concentrations in excess of 0.3 mg/l Fe and manganese levels of 0.05 mg/l Mn are considered a nuisance because their orange-brown to black precipitates cause noticeable discoloration of water and may result in staining of household plumbing fixtures and laundry. Because of this, iron and manganese are regulated by IEPA under a *secondary MCL*. A secondary MCL is directed at water constituents that create an aesthetic nuisance rather than a health hazard.

Effectiveness of Iron and Manganese Removal

Accordingly, the Oakwood Road Water Treatment Plant was designed to remove the relatively small quantity of solids formed when iron and manganese are precipitated from Wells #11 and #12. The bar chart shown below illustrates the almost total (99%) removal of iron and the 80% removal of manganese in November 2002.

Manganese removals vary owing to the addition of potassium permanganate to the filter influent. Depending upon variations in feed rate, permanganate addition adds approximately 0.25 mg/l Mn to the influent water, bringing the total to roughly 0.48 mg/l Mn. Any transient overfeed of permanganate can result in the passage of 'pink water' plus increase the manganese concentrations in the filtered water. This suggests that the permanganate feed should be reduced to the minimum consistent with the maintenance of filtered water Mn concentrations less than 0.05 mg/l.



Permanganate is added to aerated water (filter influent) to oxidize manganous ion (Mn^{++}) to $Mn(OH)_4$, a brown-black precipitate.

Horizontal pressure filters are divided into four compartments containing dual, crushed anthracite coal and coarse sand, media

Filter media probing and sampling were conducted on November 18, 2002.

Most of the severely cemented (sandy) material appeared to underlie the coal layer. The coal media also showed evidence of a loose aggregation that could be broken up by hand.

The treatment process utilized at the Oakwood plant has long been widely used in the treatment of Illinois ground waters. It consists of aeration to introduce dissolved oxygen to the well water. This oxygen readily oxidizes ferrous ion at the neutral pH (7.5) of the well water to form the familiar orange-brown precipitate, ferric hydroxide. Since manganous ion is not readily oxidized by oxygen at this pH, potassium permanganate is then added to oxidize the small quantity of manganous ion present in the source water. Shortly after this chemical addition, the water is passed through pressure filters containing crushed anthracite coal over silica sand. It is within these filter beds that chronic problems have arisen.

Condition of Filter Media

The filter media in the Oakwood plant filters is comparatively coarse. A top layer of crushed anthracite coal (effective particle diameter, D_{10}, 0.6 to 0.8 mm) sits atop a support layer of silica sand (effective diameter, 0.8 to 1.2 mm). Normally, if the silica sand was to serve as a filter medium as opposed to a support for the coal layer, it would have an effective size in the range of 0.4 to 0.6 mm. These larger sand sizes ~~would~~ require considerably higher backwash flow rates for removal of any attached deposits.

Previous analysis of encrusted materials removed (jackhammered) from the filter beds during filter restoration indicates that the media encrustants (acid-soluble materials) consist of calcium carbonate plus iron, and to a lesser degree, manganese oxides. This combination of precipitates have caused the grains of filter media to aggregate and harden. While the addition of sulfuric acid results in significant effervescence of carbon dioxide, it does not appear that the media cementation is entirely due to the deposition of calcium carbonate.

From the most recent filter media sampling it appears that it is, primarily, the underlying sand layer that is undergoing cementation. This sand has already formed a horizontal lens that is rock hard, requiring a crowbar and hammer even to recover a sample for observation and analysis. Upon acidification, 24% of this sand layer sample, by weight, was lost. This is in marked contrast with the loss of 8.5% by weight following acidification of the coal layer.

From these analytical results, one can conclude that the iron and manganese hydroxides, once removed from the flow and attached to the media during filtration, are not being uniformly and effectively removed from the media particles during the backwash process. This has resulted in the progressive aggregation of the adjoining media particles until large areas of the filter bed have become unavailable for filtration. Aerated water may then travel along filter walls, through cracks, and bypass much of the filter surface. Poorer effluent quality and shorter filter runs are operational indications of the formation of concretions and the blinding of the filter media.

At the Oakwood Plant, aggregation appears to occur, primarily, within the sand layer immediately under the upper coal layer. This might be expected since the sand layer, being far greater in density (specific gravity, 2.6) as well as larger than the coal (specific gravity, 1.6), would not expand as much, if at all, during backwash. As a result, the surface deposition of calcium carbonate and iron oxides on the sand would be less efficiently removed.

Replacement Media

Under the current circumstances, there seems to be little choice but to remove and discard the encrusted filter media before encroaching filter blockage reaches the point where water production is significantly impaired. However, the new replacement filter media should be selected so it will respond more appropriately to the filter backwash rates that can be achieved using the present system. This will require, at a minimum, the installation of a finer sand that will expand significantly during backwash. A deeper layer of 0.5 mm silica sand overlain by a shallower layer of crushed anthracite coal should improve the hydraulics of filter backwash.

Modification of Backwash for more Effective Removal of Attached Iron and Manganese Oxides

Normally, when water wash is applied exclusively for filter backwash, an expansion of 20% to 50% is used. For the Oakwood Road Plant, a filter backwash rate of 12 gpm/sf (19 in./min. rise rate) was recommended (Daily and Associates, July 13, 2001). This would result in a 50% expansion of the lighter coal layer. It was also estimated that the sand layer would expand by 10% at this wash rate. However, there would be no sand expansion at a backwash rate of 10 gpm/sf.

Frequently used supplements to 'unassisted upflow water wash alone' include air scour and surface wash. Air scour (air-assisted backwash) reportedly provides more effective scouring action, virtually eliminates mudball formation and can significantly reduce the amount of water used for backwashing. To avoid media loss, compressed air, at a rate of 1 to 2 $ft^3/min/ft^2$, is applied for up to 5 minutes prior to initiation of a low-rate backwash.

Recommendations

Replacement Filter Media

It is recommended that the replacement filter media consist, primarily, of 0.55 mm silica sand with a 6-inch cap of 6 to 8 mm coal. The final design of this replacement media should be such that the silica sand layer will be expanded by 20% or more at a backwash rate of 10 gpm/sf.

Reduction in Permanganate Addition

To minimize solids application to the filter units, the permanganate addition should be reduced to the lowest possible effective dose. To assist in manganous ion removal, additional chlorine (up to a total of 3 mg Cl/l) should be applied at the aerator to supplant a portion of the permanganate demand and preclude biological growth on the filter media.

There are several operational reasons, in addition to chemical cost savings, for limiting the addition of permanganate. Primarily, it is very difficult to maintain a constant permanganate feed concentration, particularly, when the feed rate is as low as 0.25 mg/l. Overfeed results in the passage of soluble manganese and the appearance of 'pink water' in the effluent. The accumulation of additional manganese hydroxide in the filter adds to the rate of fouling and increases the need for more vigorous (higher rate) backwash.

Installation of Air Scour

Following removal of the cemented filter media, the filter units should be outfitted with an air injection system. The distribution piping (nonmetal) for this system should be located beneath the silica sand filter layer, preferably, within the underdrain system.

The operational protocol for the air scour should include the drawdown of the water level in the filter to below the effluent launders in order to avoid loss of filter media over the effluent weirs. Although operational experience may lead to a refinement of the air-assisted backwash procedure, initially, the air should be applied at a rate of 2 $ft^3/min/ft^2$ for a period of five minutes prior to the start of backwash.

After the air is shut off, the filters should be backwashed at a rate of 10 gpm/sf until the wash water is clear. Records should be kept of the quantity of wash water required.

Annual Media Inspection

Each filter should be opened annually so that representative samples can taken of the coal and sand media. The depth of media in each filter cell should be measured to determine how much media was lost over the year.