Background

Iron and manganese are internationally known for their negative impact on drinking water aesthetics. Regulations, guidance, and/or treatment goals have been established to address the impact of iron and manganese on drinking water quality (Table 1), but may not be adequate to protect against consumer detection of off-colors or off-flavors.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Type</th>
<th>Compliance</th>
<th>Manganese</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Health Organization</td>
<td>-</td>
<td>-</td>
<td>No value</td>
<td>No value</td>
</tr>
<tr>
<td>US Environmental Protection Agency</td>
<td>Aesthetic</td>
<td>Not Enforced</td>
<td>0.05 mg/L</td>
<td>0.3 mg/L</td>
</tr>
<tr>
<td>European Drinking Water Directive</td>
<td>Aesthetic</td>
<td>Enforced***</td>
<td>50 µg/L</td>
<td>200 µg/L</td>
</tr>
<tr>
<td>Australia Drinking Water Guidelines</td>
<td>Health</td>
<td>Enforced</td>
<td>0.5 mg/L</td>
<td>None</td>
</tr>
<tr>
<td>Taiwan Environmental Protection Administration</td>
<td>Aesthetic</td>
<td>Enforced</td>
<td>0.05 mg/L</td>
<td>0.3 mg/L</td>
</tr>
</tbody>
</table>

Table 1 *(WHO, 2011) †(USEPA 2013) ‡(EC 98/83/EC 1998) **(NHMRC/ARMCANZ, 2011) †† (R.O.C. (Taiwan) Environmental Protection Administration 2009) ‡‡Required, enforced standard or, if optional, not enforced. ***In cases where exceedance may result in a risk to human health as determined by member states

Methods

Sensory Perception

1 in 5 Alternative Forced Choice

Method for Taste/Flavor and Visual

Five randomly numbered cups

One with sample

Four with reference water

Best Estimate Threshold

Logistic Regression

Lipid Oxidation

Leucoerobicline Blue (Fig 1a)

Measures manganese (III-VII)

Mn(II)= 9.84 mg/L (180 mM)

Phenanthline Method (Fig 1b)

Measures ferrous iron (II)

Fe(II) = 10 mg/L (180 mM)

Visual Results

Oxidized Fe(III) and Mn(IV) are detectable at SMCLs (Table 2, Fig 2).

Mn(IV) is still detectable at 10% of the SMCL (Fig 2a). Mn(II) solutions are colorless up to 1000 mg/L.

Fe(III) (Fig 2b) is less likely to result in off color detection than Mn(IV) at 10% of the SMCL as detection dropped to the percentage equivalent to guessing (20%).

![Figure 2](image)

<table>
<thead>
<tr>
<th>Percent of SMCL</th>
<th>Oxidized Manganese Mn(IV) (n=31)</th>
<th>Oxidized Iron Fe(III) (n=64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>60</td>
<td>97</td>
<td>84</td>
</tr>
<tr>
<td>20</td>
<td>97</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>97</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 2

Taste/Flavor Results

Fe(II) flavors (taste plus odors) (Fig 3) are detectable below current standards. An age-dependent variation demonstrates people over 50 yr have a 10-fold higher threshold than under 50 yr (Mirlohi et al., ES&T 2011).

As seen in Figure 4, Current aesthetic standards are much lower than Mn(II) population taste thresholds and therefore are sufficiently protective of taste from manganese (Sain et al., JAWWA 2014; Sain & Dietrich, AQUA 2014).

Oxidized Mn(IV) and Fe(III) do not result in off flavors at their SMCLs. The difference in taste/flavor threshold characteristics for iron and manganese are due to their ability to oxidize lipids in saliva and the oral cavity. Fe(II) causes significant lipid oxidation, which results in production of odorous volatiles that contribute odor to the Fe(II) taste (Fig 5). Mn(II) results in no lipid oxidation.

Conclusions

Current aesthetic guidelines are not sufficient to protect against consumer detection of off-color from iron or manganese. Mn(IV) is still readily detectable at 0.005 mg/L.

Elevated Fe(II) concentrations are far more likely to result in off-flavors than Mn(II), and current guidelines may not be protective of all individuals.

There is no evidence that bitter or metallic flavors should be attributed to Mn(II) or Mn(IV) at current guidelines.

Both iron and manganese should be removed to the extent possible to protect against consumer detection of off-colors and off-flavors.